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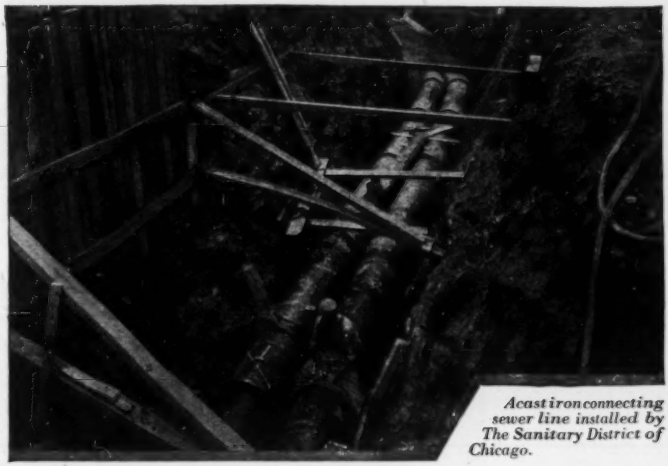

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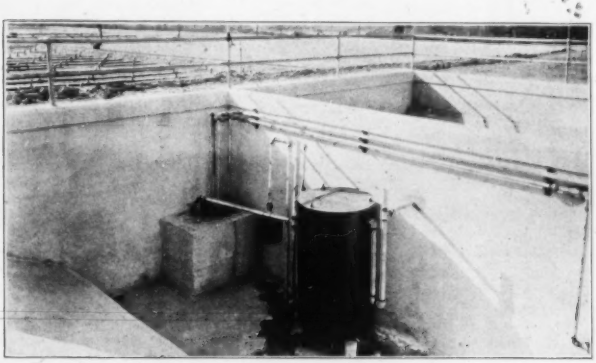

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Federation Affairs

The Determination of Dissolved Oxygen by the Winkler Method

Preliminary Report of the
Committee on Methods of Sewage Analysis
of the Federation of Sewage Works Associations

E. J. THERIAULT, *Chairman*
A. M. BUSWELL J. J. HINMAN
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The Winkler process[1] for the determination of dissolved oxygen depends on the formation of a precipitate of manganous hydroxide in a glass-stoppered bottle completely filled with the water under examination. The oxygen dissolved in the water is rapidly absorbed by the manganous hydroxide, forming a mixture of higher oxides which, on acidification in the presence of an iodide, releases iodine in a quantity chemically equivalent to the oxygen content of the sample. The liberated iodine is then titrated with a standard solution of sodium thiosulphate. Various modifications of this general procedure are available for counteracting the effect of interfering substances.

Sampling for Dissolved Oxygen

Sample bottles of the type commonly used in oxygen demand determinations (240 to 380 ml.) are very satisfactory. At the start of an investigation it may nevertheless be desirable, for convenience and uniformity, to select a 250-ml. glass-stoppered bottle (8-ounce tincture).

In general, the sampling arrangements should be such as to insure at least a three-fold displacement of the liquid in the sampling bottle without entrainment of air bubbles.[7] In sampling from streams, ponds or tanks of moderate depth, this may be accomplished by the use of apparatus of the type shown in Figures 1, 2 and 3. These sampling devices are designed for the collection of one, two or three samples which may be used, respectively, for: (1) dissolved oxygen, (2) dissolved oxygen and oxygen demand and (3) dissolved oxygen, oxygen demand and bacteriological determinations.

It will be noted that the sample bottles begin to fill as soon as the above-mentioned sampling devices are submerged. If a sample is required from

a considerable depth, it may be desirable to use a sampler provided with a valve release, as shown in Figure 4.

Selection of a Method of Procedure

Huge errors may be introduced in dissolved oxygen work (and also in oxygen demand work) by the neglect of proper precautions in the presence of interfering substances such as nitrites, ferrous salts, organic matter, sulphites, etc., or by an improper application of the various modifications of the Winkler method which are designed to overcome this type of interference.

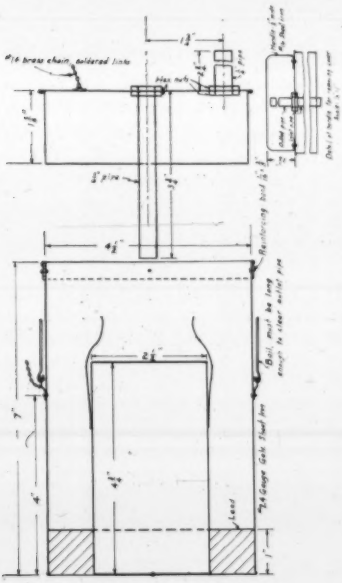

FIG. 1.

The regular Winkler procedure should be used in determining the dissolved oxygen content of pure waters. With suitable precautions this procedure may also be applied to waters containing relatively stable forms of organic matter, such as sugars, starches and cellulose.[5]

The Rideal-Stewart[2] or permanganate modification of the Winkler method should be used when appreciable amounts of nitrites[3] or ferrous salts[4,5] are present in the sample.

Interference due to nitrites may be ascribed to the cycle of reactions:

$$2HNO_2 + 2HI = N_2O_2 + 2H_2O + I_2$$

$$2N_2O_2 + 2H_2O + O_2 = 4HNO_2$$

which goes on, with the liberation of iodine and the regeneration of nitrous acid, as long as oxygen and iodide are present. As a rule nitrites will occasion erroneously high results when present in amounts exceeding 0.1 p. p. m. of N as NO_2^-. It is to be borne in mind that nitrites, although absent at the start, may appear during incubation in oxygen demand tests. Interference due to nitrites may also be expected in dealing with effluents from biological oxidation devices.

High results may be obtained in the presence of ferric salts owing to the

liberation of iodine from iodides in the final step of the Winkler process, especially if the titration is delayed.[4,5] On the other hand, one part per million of ferrous iron will occasion an apparent loss of about 0.14 p. p. m. of dissolved oxygen.

The permanganate modification is not recommended as a corrective for interference due to relatively stable forms of organic matter such as sugars, starches, etc., which are not readily acted upon by permanganate in the cold. A preliminary treatment with permanganate of samples containing

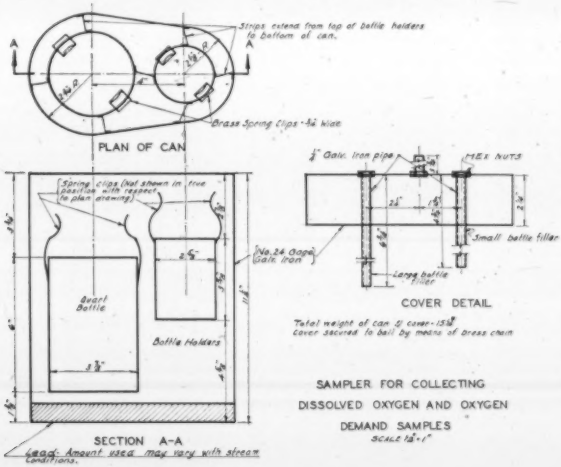
Strips extend from top of baffle holders to bottom of can.
Brass Spring Clips - 3/4 Wide
PLAN OF CAN
Spring clips (Not shown in true position with respect to plan drawing)
Board Baffle
Baffle Holders
SECTION A-A
Amount used may vary with stream conditions.
1/2" Galv. Iron pipe
1/2 Ex. NUTS
Small baffle filler
(No. 24 Gage Galv. Iron)
Large baffle filler
COVER DETAIL
Total weight of can & cover-15#
Cover secured to bail by means of brass chain
SAMPLER FOR COLLECTING
DISSOLVED OXYGEN AND OXYGEN
DEMAND SAMPLES
SCALE 1" = 1"

FIG. 2.

such substances is unprofitable and may actually be detrimental. The permanganate modification also fails in the presence of sulfite wastes.

The alkaline-hypochlorite modification[6] should be used when the sample contains sulphites, thiosulphates, polythionates, free chlorine or hypochlorites. (Paper mill wastes, chlorinated effluents, etc.)

The Standardization of Thiosulphate Solutions

The following reagents and solutions are required:

1. Starch Solution.—About 0.5 per cent. Grind 5 or 6 grams of arrowroot starch in a mortar with a small quantity of water. Pour into 1 liter of boiling water, stir and allow to settle overnight. Use the clear supernatant.

2. Dilute Acid for Standardization.—1.8 M H_2SO_4 approximately. (One volume of concentrated sulphuric acid poured into 9 volumes of water.)

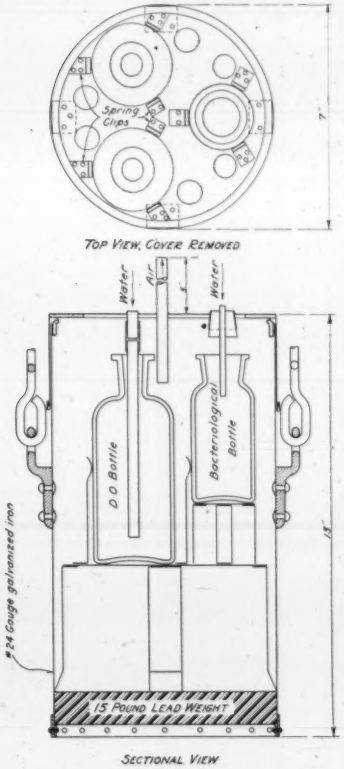

FIG. 3.—Sample Collector—Type A.

3. Potassium or Sodium Iodide Crystals.—Free from iodates.

4. Stock Sodium Thiosulphate Solution.—24.82 Grams of $Na_2S_2O_3.5H_2O$ per liter, corresponding to a 0.1 M solution. The solution may be preserved: (1) by the addition of ammonium carbonate (1.5 grams per liter) and chloroform (5 ml.* per liter *after* making up to the mark), or (2) by the addition of 1 M NaOH at the rate of 4 ml. per liter.

5. Standard Sodium Thiosulphate Solution.—0.025 M. Prepared by diluting 250 ml. of stock thiosulphate solution (0.1 M) to 1 liter or by weighing out 6.205 grams of $Na_2S_2O_3.5H_2O$ making up to 1 liter with distilled water.

The keeping qualities of the 0.025 M thiosulphate solution are somewhat improved by the addition of 5 ml. of chloroform after making up to the mark. The chloroform also serves to keep the burettes clean. This solution, however, will deteriorate quite rapidly and should be made up fresh every few weeks. The strength of the solution may be checked with a standard solution of biniodate or bichromate.

6. Potassium Biniodate Solutions.—A stock solution of strength

* The abbrevation "ml." for milliliter or milliliters is used throughout instead of "cc."

equivalent to that of the 0.1 *M* thiosulphate contains 3.250 grams of $KIO_3 \cdot HIO_3$ per liter in accordance with the following reaction:

$$2KIO_3 \cdot HIO_3 + 20KI + 11H_2SO_4 = 11K_2SO_4 + 12H_2O + 12I_2$$

A biniodate solution equivalent to the 0.025 *M* thiosulphate solution contains 0.8124 gram of $KIO_3 \cdot HIO_3$ per liter and may be prepared by diluting 250 ml. of the stock biniodate solution to 1 liter.

Potassium biniodate (acid iodate) can readily be obtained sufficiently pure for direct weighing without further purification, and its keeping qualities both in the dry state and in solution leave little to be desired. The titration is exactly the same as when potassium permanganate or bichromate is used for the standardization of thiosulphate solutions.

Apart from their uses for standardization, these biniodate solutions are also convenient for back titrations, in case of overruns, both in the regular procedure and in the hypochlorite modification.

Potassium bichromate may be substituted for potassium biniodate if difficulty is experienced in securing the latter reagent. A solution of potassium bichromate equivalent to the 0.1 *M* sodium thiosulphate should contain 4.903 grams of $K_2Cr_2O_7$ per liter.

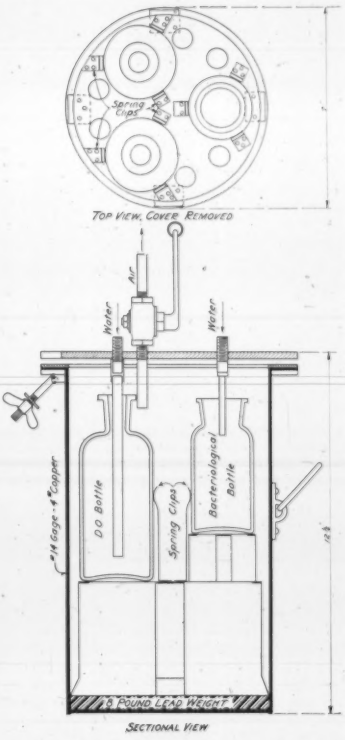

FIG. 4.—Sample Collector—Type B.

For the standardization about 5 grams of potassium iodide (free from iodate) are dissolved in a 250-ml. Erlenmeyer flask with a small quantity of distilled water and 10 ml. of dilute sulphuric acid (1:10) are added, followed by 40.00 ml. of standard biniodate (or bichromate) solution. The

liberated iodine is then titrated with the thiosulphate solution, adding starch toward the end of the titration when a pale straw color is reached. Exactly 40.00 ml. of thiosulphate should be required when the solutions under comparison are of equal strength.

Reagents for the Winkler Method

The following solutions are required when the unmodified Winkler procedure is used:

1. **Manganous Sulphate Solution.**—480 Grams of $MnSO_4.4H_2O$ or 400 grams of $MnSO_4.2H_2O$ dissolved in distilled water, filtered and made up to 1 liter. When uncertainty exists regarding the water of crystallization, a solution of equivalent strength may be obtained by adjusting the specific gravity of the solution to a value of 1.270 at 20° C. The manganous sulphate solution should liberate only traces of iodine when added to an acidified solution of potassium iodide. (Absence of manganic and ferric salts.)

2. **Alkaline-Iodide Reagent.**—500 Grams of NaOH (or 700 grams of KOH) and 135 grams of NaI (or 150 grams of KI) per liter. Potassium and sodium salts may be used interchangeably. The reagent should be practically free from carbonates. It should not give any color with starch when diluted and acidified. (Absence of nitrites, iodates and ferric salts.)

3. **Concentrated Sulphuric Acid.**—Specific gravity, 1.83–1.84. The strength of this acid is about 18 *M* (36 *N*). Hence 1 ml. is equivalent to about 3 ml. of the alkaline iodide solution.

Reagents for the Permanganate (Rideal-Stewart) Modification

The following solutions should be prepared when the permanganate modification of the Winkler method is to be used as a preliminary treatment for the destruction of nitrites:

1. **Potassium Permanganate Solution.**—6.32 Grams of $KMnO_4$ per liter.

2. **Oxalate Solution.**—2 Grams of potassium oxalate, $(COOK)_2.H_2O$, in 100 ml. of distilled water. One ml. of this oxalate solution will suffice for the neutralization of about 1.1 ml. of the permanganate solution. Under certain conditions this solution deteriorates rapidly. An oxalic acid solution of equivalent strength (1.4 grams of $(COOH)_2.2H_2O$ in 100 ml. of distilled water) may be used.

In the presence of appreciable amounts of iron salts, the following solutions will also be required:

1. **Fluoride Solution.**—40 Grams of $KF.2H_2O$ dissolved in distilled water and made up to 100 ml.

2. **Phosphoric Acid.**—85 Per cent H_3PO_4.

Reagents for the Alkaline-Hypochlorite Modification

The following solutions are required when the alkaline-hypochlorite modification is applied for the oxidation of sulphites, thiosulphates, etc.:

1. **Alkaline-Hypochlorite Solution.**—1 *M* NaOCl and 0.1 *M* NaOH. This solution may be prepared by passing chlorine gas through a 2.1 *M* NaOH solution, with cooling, until a 1 ml. test portion of the chlorinated solution requires about 20 ml. of 0.1 *M* thiosulphate for the neutralization of the iodine released upon acidification in the presence of an iodide.

The pharmaceutical preparation "Hyclorite," if fresh, is approximately molar in respect to hypochlorite. On adding 1 volume of 1 *M* NaOH to 9 volumes of "Hyclorite," a precipitate of $Ca(OH)_2$ is formed, which settles out readily. The supernatant liquor is in reasonable conformity with the above specifications.

The alkaline-hypochlorite solution should be kept tightly stoppered when not in use and its strength should be checked at least every week.

2. **Iodide Solution.**—1 *M* KI or NaI. Prepared by dissolving 17 grams of KI or 15 grams of NaI in distilled water and making up to 100 ml. This solution should be preserved by the addition of 1 ml. of 1 *M* NaOH to each 100 ml. of solution.

3. **Sodium Sulphite Solution.**—0.05 *M* (0.1 *N*). Contains 6.3 grams Na_2SO_3 per liter.

The Winkler Method

The following procedure is applicable to the determination of dissolved oxygen in the absence of unstable forms of organic matter and of such readily oxidizable mineral substances as nitrites, ferrous salts, polythionates, etc.

The volume of Winkler reagents to be added is based on the assumption that bottles of the size recommended herein (250 ml.) are being used. With larger bottles (300 to 380 ml.), 2 ml. each of the Winkler reagents should be used. With smaller bottles (125 ml. or less), it will be sufficient to add 0.5 ml. each of the three Winkler reagents (manganous sulphate solution; alkaline-iodide solution; concentrated sulphuric acid).

Procedure

1. Add 1 ml. each of the manganous sulphate and alkaline-iodide solutions.

For the sake of minimizing the loss of dissolved oxygen by oxidation of organic materials at high pH values, the manganous sulphate solution should be added first. These reagents should be added well below the surface of the liquid so as to avoid loss of precipitate on replacing the stopper.

2. Shake well, by inverting the bottle several times, so as to distribute the precipitate uniformly throughout the bottle.

In the absence of large amounts either of mineral salts or of organic matter, the period of standing in the presence of alkaline-iodide is unimportant. Under this condition it is permissible to pass from one bottle to another of a series of parallel determinations, allowing each precipitate to settle until it is contained in the lower half of the bottle. As the precipitate settles readily, the dissolved oxygen in the upper part of a bottle will not be completely absorbed unless the period of shaking is suitably prolonged. If uncertainty exists on this point, or else if a clear supernatant is not obtained, the shaking should be repeated. This precaution should especially be borne in mind when reduced amounts of reagents are used.

Dissolved mineral salts may act to depress the pH value of the alkaline-iodide mixture, thereby greatly increasing the time required for the complete absorption of dissolved oxygen by the manganous hydroxide. With sea water a 10-minute period of contact with the manganous hydroxide may be required.

Numerous forms of organic matter are capable of direct oxidation by dissolved oxygen at pH values of 12 or thereabouts (corresponding to the degree of alkalinity obtained when alkaline-iodide is added to a sample). Although the reaction in question proceeds somewhat slowly, low results may be obtained if the period of standing in the presence of alkaline-iodide is unduly prolonged. For this reason the test should be carried through on individual samples when interference by organic matter is suspected and the period of alkalinization should be reduced to the minimum time consistent with the complete absorption of dissolved oxygen.

When 1 ml. of manganous sulphate solution is used with 250 ml. of sample it may safely be assumed that the absorption of dissolved oxygen will be practically complete if the precipitated manganous hydroxide is agitated *continuously* for 40 to 50 seconds. With 2 ml. of manganous sulphate, a shorter period of shaking (20 to 25 seconds) is sufficient. If the sample is then acidified as soon as the precipitate has settled, accurate results will be obtained in the presence of organic matter in amounts corresponding to 1000 parts per million of either dextrose or peptone.

Larger amounts of organic materials may be present (say 5000 p. p. m. or 0.5 per cent of dextrose) without introducing an appreciable error, if the sample is acidified before the precipitate has settled (that is, immediately after shaking), suitable allowance being made for the slight loss of precipitate by displacement on adding the acid. This procedure should be followed with sulphite wastes.

3. Acidify with 1 ml. of concentrated sulphuric acid, allowing the acid to run down the neck of the bottle.

The use of hydrochloric acid is contraindicated in the presence of iron salts,

4. *To avoid the reduction of manganic salts by organic materials,* it is desirable that the sample be shaken as soon as possible after the addition of acid when organic substances are present.

The liberated iodine diffuses slowly. It should be uniformly distributed throughout the bottle before withdrawing an aliquot part of the sample for titration.

5. *In the absence of ferric salts* and certain forms of organic matter (acetic acid, for example), it may be possible to delay the titration for several days without introducing an appreciable error.

The titration may be delayed for one hour, even in the presence of 100 p. p. m. of ferric iron, if potassium fluoride has been added in the preliminary treatment. In the absence of fluoride, the titration should be performed *immediately* after the final acidification when the ferric iron content exceeds, say, 10 p. p. m.

The titration may be delayed for several days, even in the presence of 100 p. p. m. of iron, if phosphoric acid (4 ml. of 85 per cent H_3PO_4) is substituted for sulphuric acid in the final acidification.

6. *A correction for the loss of dissolved oxygen* by displacement with the reagents should be applied to the amount measured out for titration. Thus, when 1 ml. each of the manganous sulphate and alkaline-iodide reagents are added to a 250-ml. bottle, the amount measured out for titration should be:

$$200 \times \frac{250}{250 - 2} = 201.6 \text{ ml.}$$

if it is desired to titrate 200 ml. of the original sample. No correction need be applied for the sulphuric acid unless the addition of this reagent has occasioned a loss of precipitate.

When the preliminary treatment with permanganate has been used, a correction should be applied for the following volumes of added reagents:

0.7 ml.	of concentrated H_2SO_4
1.0 "	" 0.2 N $KMnO_4$
3.0 "	" alkaline-iodide solution
1.0 "	" manganous sulphate solution
5.7 ml.	

When 250-ml. bottles are used, the amount measured out for titration should be:

$$200 \times \frac{250}{250 - 5.7} = 204.7 \text{ ml.}$$

if it is desired to titrate 200 ml. of the original sample.

The assumptions made in deriving this correction factor are only partly correct, as some of the reagents undoubtedly contain dissolved oxygen. No correction has been made for the addition of the oxalate solution, as it

is presumably saturated with dissolved oxygen. A correction of this magnitude about balances the tendency of the oxalate to give low results.

For many purposes the titration of 100 ml. of sample will give sufficiently accurate results. In some laboratories, however, greater accuracy is secured by conducting the titration in the bottle itself after removing a portion of the iodine solution such that a convenient aliquot part of the original sample is left in the bottle.

7. *Titrate with 0.025 M thiosulphate* until the amount of iodine remaining is equivalent to about 0.5 ml. of thiosulphate solution, corresponding to a pale straw color in the sample.

8. *Add 1 or 2 ml. of freshly prepared starch solution* and titrated rapidly to the first disappearance of the blue color. Subsequent recolorations owing to the presence of traces of iron salts or to the catalytic effect of nitrites, etc., should be disregarded.

9. *When several samples are being run at the same time*, four or five aliquot portions may be poured out at one time if the titrations are not delayed, provided that iron salts and nitrites are not present in more than traces.

The loss of iodine by diffusion into the air is appreciable if the oxygen content exceeds, say, 7 p. p. m. and the titration is unduly delayed.

10. *When the volume titrated* is equivalent to 200 ml. of the original sample, the dissolved oxygen content in parts per million is numerically the same as the required volume of 0.025 *M* thiosulphate expressed in milliliters. In general,

$$\text{P. p. m. of dissolved oxygen} = \frac{200\ (\text{ml. of } 0.025\ M \text{ thiosulphate})}{(\text{ml. of sample titrated})}$$

11. *Example:* If 100 ml. of sample require 4.50 ml. of 0.025 *M* thiosulphate, the dissolved oxygen content is

$$\frac{200}{100} \times 4.50 = 2 \times 4.50 = 9.00 \text{ p. p. m.}$$

The Permanganate Modification

The permanganate (Rideal-Stewart) modification of the Winkler method should be used in determining the dissolved oxygen content of partly nitrified effluents and, in general, whenever the sample contains 0.1 p. p. m. or more of nitrogen as nitrite. Through the use of fluorides and of phosphoric acid the applicability of the permanganate modification may also be extended to mine wastes and other samples containing large amounts (100 p. p. m. or more) of iron.

Procedure

All reagents, excepting the sulphuric acid, should be added well below the surface of the liquid:

1. Add 0.7 ml. of concentrated sulphuric acid. It is important that the amount called for should not be exceeded. The 0.7 ml. portion, for that reason, is best added with a 2-ml. pipette.

2. Add enough of permanganate solution to obtain a violet tinge which persists after shaking.

With samples whose behavior is fairly well known, the proper amount of permanganate may be added all at once.

With samples of unknown or variable composition, trial amounts (1 ml. or less) should be added with shaking and a suitable delay allowed between additions. When an additional amount of permanganate appears necessary, it should be added while a faint violet tinge still persists (that is, before the appearance of brownish colorations due to intermediate oxides).

To avoid too great a dilution of the sample, a stronger solution of permanganate should be used when large amounts (5 ml. or more) of this reagent are required.

An attempt should be made to keep the amount of permanganate added down to a minimum and the probable excess of this reagent in the solution should be noted.

3. In practice, a period of standing of five minutes at ordinary temperatures after obtaining a permanent violet coloration is sufficient to reduce the nitrite content to a value which will not cause undue interference.

The longer period of standing of 20 minutes which is sometimes recommended appears to be based on results obtained in titrations of nitrites with permanganate solutions and it probably refers to the time which must be allowed for the complete oxidation of the nitrites.

The oxidation by permanganate solutions of ferrous salts and of sulphides is practically instantaneous. A period of standing of one-half minute should suffice in such cases.

4. Potassium oxalate solution is added to destroy the excess of permanganate whenever the oxidation of the interfering substances (readily oxidizable materials) is judged complete.

As a trial amount which should not be greatly exceeded, it is recommended that 0.5 ml. of the 2 per cent oxalate solution be first added. If after standing for five minutes the color of permanganate still persists, an additional 0.5 ml. portion should be added. When the directions regarding the addition of permanganate have been followed, this second portion should induce complete decoloration.

When a large excess of oxalate is added, the period of decolorization is lengthened and the results obtained are too low.

It is important that perfect decolorization be secured, as even a trace of brownish coloration will react with iodides on acidification, giving results which may be entirely too high. Apparent increases in dissolved oxygen

content during incubation, as in oxygen demand studies, may frequently be traced to this source of error.

In the presence of iron salts, decolorization is delayed to a surprising extent (24 hours under certain conditions), even when the correct amount of oxalate has been added. In order to hasten the decolorization when iron salts are known to be present, potassium fluoride (2 ml. of 40 per cent solution) should be added along with the permanganate or at any other stage of the preliminary treatment.

For the reason that ferric salts in the presence of oxalates are readily reduced to the ferrous condition by light (very rapidly so in direct sunlight), the decolorization should proceed in the dark when iron salts are present in appreciable amounts.

5. *When the permanganate is fully decolorized*, add 1 ml. of manganous sulphate solution followed by 3 ml. of alkaline-iodide reagent. Do not add less than the indicated amounts.

It will be noted that approximately 2 ml. of alkaline-iodide reagent are required for the neutralization of the 0.7 ml. portion of concentrated sulphuric acid added at the start, leaving 1 ml. for combination with the manganous sulphate. The amount of iodide added, however, is three times greater than when 1 ml. each of the two reagents is used. The extra amount of iodide is beneficial in repressing the deleterious effect of the oxalate and, presumably, of other forms of organic matter as well.

The foregoing steps constitute the preliminary treatment of a sample for the destruction of nitrites, sulphides, etc., and for the oxidation of ferrous salts to the ferric condition. The subsequent treatment is the same as when the Winkler method is used, starting with the shaking of the sample after the addition of the Winkler reagents. (See 2, under "Procedure," for the Winkler method.) It should not be assumed that organic materials are absent when the permanganate treatment has been used.

The Alkaline-Hypochlorite Modification

Polythionates and similar compounds in paper mill wastes break down readily in alkaline solution to form sulphites and thiosulphates. The oxidation of such compounds must, therefore, be carried to the formation of sulphates before the addition of the alkaline-iodide solution. A preliminary treatment, according to the Rideal-Stewart modification, is ineffective as the oxidation to sulphates of sulphites, thiosulphates and polythionates is incomplete when permanganate is used. The error with samples containing 0.25 per cent of digester waste from the manufacture of sulphite pulp may amount to 7 or 8 parts per million of dissolved oxygen, the results appearing too low. With such samples a practical degree of accuracy may be secured through preliminary treatment with hypochlorite and iodine, as described below. At best, however, this procedure gives low results, the

error with 0.25 per cent of digester waste amounting to about 1 part per million. Delays at any stage of the process should be avoided.

The procedure given below consists in a preliminary treatment of the sample with an alkaline solution of sodium hypochlorite for the decomposition of polythionates and for the oxidation of sulphites, thiosulphates, etc., to sulphates. The subsequent treatment (see "3" below, under "Procedure") calls for the removal of the undecomposed hypochlorite through the liberation of iodine which is in turn removed with a dilute solution of sodium sulphite. Dissolved oxygen may then be determined by the regular Winkler procedure.

Residual Chlorine

Beginning with "3" the procedure given below should also be used when dissolved oxygen is to be determined in samples containing free chlorine or hypochlorites. For the reason that tetrathionates are readily decomposed in alkaline solution, sodium thiosulphate should not be used for the removal of iodine liberated from iodides by free chlorine and its compounds.

A preliminary treatment with hypochlorite is effective in counteracting interference due to nitrites or ferrous salts although, for this purpose, it is perhaps simpler to use the permanganate treatment.

Procedure

1. Add enough of the alkaline-hypochlorite reagent (1 *M* NaOCl and 0.1 *M* NaOH) to oxidize the sample, avoiding a great excess.

With river water polluted with sulphite waste, 0.2 ml. of the alkaline-hypochlorite reagent may be added as a trial amount. In oxygen demand work, add 1 ml. of hypochlorite solution for each ml. of digester waste present in the bottle under examination.

2. Mix well by inverting rapidly a few times. The duration of this treatment should not greatly exceed 20 seconds.

If the period of contact with the alkaline-hypochlorite is unduly prolonged, low results will be obtained, owing to the absorption of dissolved oxygen by the decomposition products of the organic matter.

3. Acidify the sample by adding 1 ml. of 1.8 M H_2SO_4 (10 per cent solution) and add 1 ml. of *M* KI (or NaI) to release iodine. Shake.

4. Neutralize the liberated iodine with 0.05 M sodium sulphite, using 0.2 ml. of starch solution as an inside indicator. If the end point is overstepped, the blue color should be restored with 0.1 ml. portions of potassium biniodate solution of equivalent strength.

The reaction between sulphites and iodine to form sulphates is complete only in very dilute solution. Under the given experimental conditions the results will be relatively low when more than 3 ml. of 0.1 *N* sulphite are required for the neutralization of the iodine. On the other hand,

if only 0.1 ml. or thereabouts of 0.1 *N* sulphite are required, it may be assumed that an insufficient amount of alkaline-hypochlorite has been used.

5. *Add 1 ml. of manganous sulphate solution and 1.3 ml. of alkaline-iodide solution.*

A slight excess of the alkaline-iodide reagent is used in order to neutralize the acid added during the preliminary treatment.

For the subsequent treatment see 2, under "The Winkler Method," beginning with the shaking of the sample.

Schematic Outline for Dissolved Oxygen Determination

For convenience of reference, the following outline has been prepared by condensing the detailed instructions given above:

The Winkler Method

1. When a preliminary treatment is unnecessary the test is started by adding 1 ml. each of the manganous sulphate and alkaline-iodide solutions. Lesser amounts may be added under certain conditions.

When a preliminary treatment with permanganate has been applied, add 1 ml. of manganous sulphate and 3 ml. of alkaline-iodide reagent.

When the alkaline-hypochlorite modification has been used, add 1 ml. of manganous sulphate and 1.3 ml. of alkaline-iodide.

2. In the practical absence of organic matter it is permissible to shake each bottle vigorously, passing from one bottle to another of a series. A second shaking is advisable. In the presence of much organic matter, treat each sample individually as directed in detailed instructions.

3. Acidify with concentrated sulphuric acid.

4. Distribute the liberated iodine uniformly throughout the bottle.

The Titration

5. In general, the titrations should be commenced within one hour after the final acidification. (See detailed instructions for tolerance in special cases.)

6. For the titration it is convenient to pour out a portion of the iodine solution which corresponds to 100 or 200 ml. of the original sample.

7. Titrate to a pale straw color with 0.025 *M* thiosulphate.

8. Add 1 or 2 ml. of starch solution and titrate rapidly to the first disappearance of the blue color, neglecting subsequent recolorations.

9. The titration should not be delayed, once the sample has been poured out.

Computations

10. In general,

$$\text{P. p. m. of dissolved oxygen} = \frac{200\ (\text{ml. of } 0.025\ M \text{ thiosulphate})}{(\text{ml. of sample titrated})}$$

Preliminary Treatment with Permanganate and Fluoride

1. Add 0.7 ml. of concentrated sulphuric acid.
2. Add enough of permanganate solution to obtain a violet tinge.

Add 2 ml. of fluoride solution if appreciable amounts of iron salts are present.

3. Allow to stand until the reaction of the permanganate with readily oxidizable substances is judged complete (5 minutes or less).
4. Decolorize with the minimum possible amount of oxalate solution. The decolorization should proceed in the dark when iron salts are present.
5. The subsequent treatment of the sample is the same as when the regular Winkler method is used.

Preliminary Treatment with Alkaline-Hypochlorite

1. Add a suitable amount of alkaline-hypochlorite reagent.
2. Shake for 20 seconds.
3. Add 1 ml. each of 1.8 *M* H_2SO_4 (10 per cent solution) and 1 *M* KI. Shake.
4. Add 0.2 ml. of starch solution and neutralize the iodine with 0.05 *M* (0.1 *N*) sulphite solution, restoring the blue color with 0.1 ml. portions of biniodate solution of equivalent strength.
5. The subsequent treatment of the sample is the same as when the regular Winkler method is used.

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Sewage Research

Heat and Energy Relations in the Digestion of Sewage Solids
II. Mathematical Formulation of the Course of Digestion

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In the past, the speed with which sewage solids digest has generally been expressed in terms of the time elapsing between their introduction into the digestion unit and their removal as "well-digested sludge." While there are various definitions of what constitutes well-digested sludge, none of them is sufficiently rigid to remove the determination of "digestion time" from the realm of individual choice. One reason for this dilemma is that the process is never "complete" in the true sense of the word. Digestion gradually approaches completeness; it becomes complete enough for ordinary purposes, but it has no definite endpoint.

The obvious way out of the difficulty of defining the rate of decomposition is to see whether or not the course of digestion can be formulated as a whole. With this in view, the authors have studied the results obtained by them in a series of experiments on sludge digestion, conducted during the past three years. It is the purpose of this paper to show that, using gas production as a measuring stick of digestion, the course of anaerobic decomposition of sewage solids can be formulated mathematically and consequently defined by certain equational constants.

Experimental Apparatus and Procedure.—Since the success of formulating the course of sludge digestion must depend upon the precision of the experiments that underly the study, brief mention will be made of the apparatus and methods employed. A second reason for doing this is that several features of the equipment developed for use in the experiments have not been previously described. As outlined in Figure 1, the digestion chamber is a 4-liter Pyrex bottle immersed in water in a 10-gallon crock. Heat is supplied to the water by means of an incandescent lamp covered with lead foil, and cooling by surface evaporation is reduced by covering the water with a layer of viscous oil. The temperature is held constant within 0.1° F. by a mercury-alcohol thermostat in a battery circuit which actuates a relay controlling the flow of current from the power circuit to the in-

candescent lamp. A small stirring mechanism keeps the temperature uniform within the bath.

The gases liberated by the digesting sludge are collected in a calibrated, cylindrical glass vessel connected, by means of rubber tubing, to a spherical glass expansion or leveling reservoir. The gas-collection apparatus is filled with a saturated solution of salt, which restricts the solubility of the

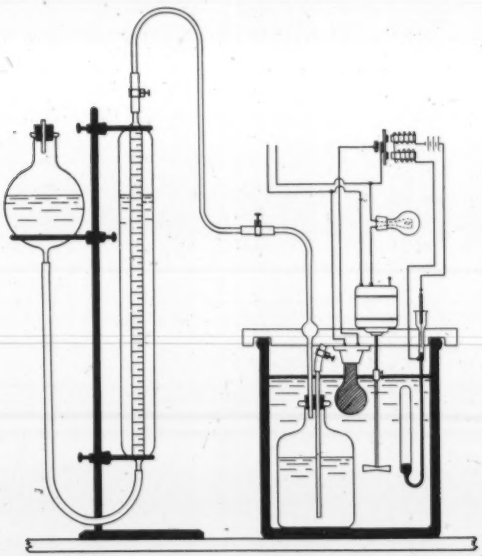

FIG. 1.—Experimental Apparatus for the Determination of Gas Production During the Digestion of Sewage Solids at a Constant Temperature.

gases in the confining liquid. This fact, together with the length of the diffusion path from the gas through the liquid to the atmosphere reduces loss by diffusion to a negligible quantity.

The equipment is simple to operate, inexpensive and rugged. Its cost, including the stirring motor, was under $10 per unit.

Experimental observations included the determination of the fuel value and of the solid- and volatile-matter content of the sludge before and after digestion; the measurement of the progressive amounts of gas produced

during digestion; the analysis of the gases collected; and the determination of the pH values of the sludge during digestion.

Choice of Gas Production as the Yardstick of Digestion.—The decomposition of sewage solids is a mass phenomenon associated with the play and interplay of many different forces, physical, chemical and biological in origin. Hence, the course of decomposition may be studied either at the hand of measurements made with a single yardstick of mass activity or by a combination of different measurements made with the yardsticks of individual activities. Since our present knowledge of the process does not permit the isolation of individual activities, however, we must, for the time being, be satisfied with a mass measurement and mass formulation of the course of decomposition.

In the case of the *aerobic* decomposition of sewage matters, a satisfactory

TABLE I

CUMULATIVE GAS PRODUCTION

Elapsed Time, Days	Gas Produced—Liters per Kg. of Raw Volatile Solids		
	CH_4	CO_2	Total
3.71	9.9	21.4	31.3
7.96	27.3	46.3	73.6
11.08	70.6	85.8	156.4
12.96	132.0	123.5	255.5
15.71	230.5	161.5	392.0
17.67	291.0	181.0	472.0
19.71	339.0	194.5	535.5
21.88	376.5	204.5	581.0
23.92	397.0	210.5	607.5
27.92	419.0	216.0	635.0
28.92	424.0	218.0	642.0
34.96	437.0	221.0	658.0
41.75	448.0	223.5	671.5

yardstick of mass activity has been found in the determination of biochemical oxygen demand, and the workers in the stream-pollution laboratory of the U. S. Public Health Service at Cincinnati, in particular, have shown in a remarkable series of researches how this parameter can be employed to define mathematically the course of deoxygenation of polluted waters or of the oxygen consumption of sewage sludges.

In the study of *anaerobic* decomposition of sewage matters, or sludge digestion, there have been developed, so far, only two parameters that seem to measure the course of digestion as a mass phenomenon. They are: (1) gas production, and (2) volatile-matter reduction. Of the two, gas production is most closely associated with the changes in energy content of the sewage solids. Hence it constitutes on the whole a better parameter of sludge digestion than does volatile-matter reduction. For this reason it is employed in this paper, and it will be shown that its use is justified.

Basic Observations.—A single representative experiment taken from a series of 46 will be chosen to exemplify the formulation of the course of digestion. This experiment comprised the digestion, at a temperature of 95° F., of plain-sedimentation sludge from Fitchburg, Mass., after seeding it with well-digested sludge. The latter had been previously produced at the same temperature from raw solids seeded with Imhoff sludge, both from Fitchburg, Mass. The basic observations on gas evolution are given in Table I.

The results for total gas production are plotted in Figure 2 against time.

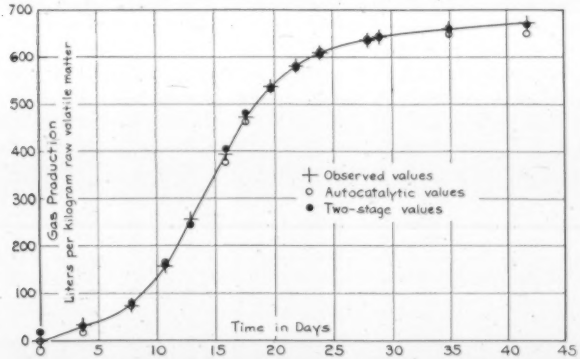

FIG. 2.—Observed Course of Sludge Digestion as Traced by Gas Production, Together with Computed Points Based Upon an Autocatalytic Equation and a Two-Stage Formulation.

A smooth curve, typical of digestion as measured by gas production, is obtained.

At the end of the experiment, gas production had practically ceased. During the course of digestion, very little, if any, gas other than methane and carbon dioxide was produced.

Mathematical Formulation

As shown in Figure 2, the course of sludge digestion, as traced by cumulative gas production, is an S-shaped, or ogee, curve. This means that, from the beginning of the process to a point in time when about half of the total amount of gas has been evolved, the yield of gas in a unit of time becomes progressively greater; while after this point has been reached, the yield becomes constantly less and the limit of gasification is gradually approached, although it may never be reached.

A number of different equations can be developed to define behavior of

this kind. One of these—the equation of a unimolecular reaction accelerated by the catalytic action of the products of the reaction—will be presented as apparently interpreting mathematically the kinetics of the sludge-digestion process. A second formulation, consisting of a combination of two discontinuous equations, will be proposed, however, for use in engineering studies of sludge digestion.

The Concept of Reaction Velocity.—It is a principle of physical chemistry that the speed with which a chemical reaction is accomplished is a function of the concentration of the reacting substances. If two or more substances are involved, the reaction velocity is generally determined by the relative concentration of each of the reacting substances. If, however, all but one of the substances are present in great excess, the reaction velocity is controlled by the concentration of that one substance alone and varies in proportion to it. Chemists call this a unimolecular reaction.

So far as the rate of decomposition of sewage matters is concerned, it is obvious that the individual reactions which compose the process of decomposition may be, and probably are, highly complex. The progress of decomposition as a whole, however, is largely a function of the concentration of the organic matter remaining to be decomposed. Hence it may be expected to possess the essential characteristics of a unimolecular reaction.

The following symbols will be employed:

G = amount of gas produced, or digestible organic matter decomposed, in time t;
L = total amount of gas generated during digestion, or digestible organic matter present at the beginning (limit of gasification or digestion);
$L_t = L - G$ = amount of gas remaining to be produced, or digestible organic matter remaining to be decomposed, after digestion has proceeded for time t;
k_1 and k_2, or K_1 and K_2 = constants of gasification, or digestion;

The differential equation defining gasification as a unimolecular reaction is:

$$-\frac{dL_t}{L_t} = k'dt \qquad (1a)$$

Expressed in words, this equation states that the increase in gas production in a differential increment of time (dt), as measured by the decrease in gasifiable material ($-dL_t$), is proportional to L_t, the amount of gasifiable material remaining. Integration and transformation to common logarithms results in the equation:

$$\log L_t = \log (L-G) = -kt + C \qquad (1b)$$

It is obvious that this equation does not describe an S-shaped curve; for as time, t, progresses arithmetically, the gasifiable material remaining, L_t or $(L-G)$, decreases logarithmically. The rate of gasification or digestion, therefore, cannot be simply proportional to the amount of

gasifiable or digestible material remaining. Some other factor must exert a controlling influence.

As in the case of many other processes, in which enzymes play a part, the unimolecular reaction underlying sludge digestion is presumably catalyzed by the products of the reaction. The chief active products are probably the enzymes that are associated with the process. The factor exerting a controlling influence, therefore, is one of autocatalysis.

Introduction of the factor of autocatalysis changes the differential equation previously noted to the following form:

$$\frac{dG}{L_t} = k_1 dt + k_2 G dt \qquad (2a)$$

This equation states first that the increase in gas production (dG), in a differential increment of time (dt), is proportional to L_t, the amount of gasifiable material remaining; second, that this increase is augmented in proportion to G, the amount of gas that has been produced; or in other words, in proportion to the products of the reaction.

After integration between the limits $t = 0$ and $t = t$ and $G = 0$ ($L_t = L$) and $G = G$ ($L_t = L_t$), the autocatalytic equation is commonly written as follows:

$$t = \frac{1}{k_1 + k_2 L} \log e \frac{L(k_2 G + k_1)}{k_1 L_t} = \frac{2.303}{k_1 + k_2 L} \log \frac{L(k_2 G + k_1)}{k_1 L_t} \qquad (2b)$$

This equation describes an S-shaped curve originating at $G = 0$ ($L_t = L$), $t = 0$ and possessing a point of inflection at:

$$G = \frac{1}{2}\left(L - \frac{k_1}{k_2}\right) \qquad (2c)^*$$

$$t = \frac{2.303}{k_1 + k_2 L} \log \frac{k_2}{k_1} L \qquad (2d)^*$$

The process begins at a slow rate. As it continues, the rate increases due to the catalyzing influence of the products of the reaction. At the same time, however, the gasifiable material is being used up. Hence gas production per unit time after rising to a maximum drops off and finally approaches zero; but the limiting value (L) is never reached.

Autocatalytic Formulation.—By a series of mathematical transformations Equation (2b) becomes:

$$\log \frac{L_t}{L\left(G + \frac{k_1}{k_2}\right)} = \log \frac{k_2}{k_1} - (k_2 L + k_1) t \log e \qquad (2e)$$

In this form it lends itself readily to the graphic determination of the constants k_1 and k_2 by a series of approximations.

* Since Equation (2a) possesses a maximum identified by $\frac{d[(k_1 + k_2 G)(L - G)]}{dG} = 0$, or $k_2 L - k_1 - 2k_2 G = 0$.

For a first approximation log $\frac{L_t}{LG}$ may be plotted against t, assuming a value of L close to the observed maximum. If the process studied is unimolecular and autocatalytic, a straight line results with slope of $-(k_2L + k_1)\log e$ and ordinate at $t = 0$ of log $\frac{k_2}{k_1}$. The data for total gas production presented in Table I are plotted in this manner in Figure 3. A straight line

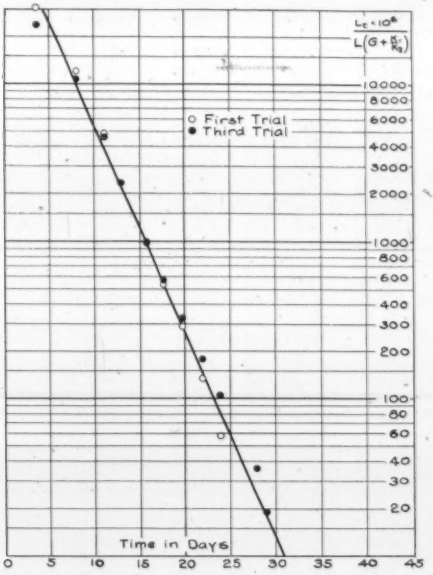

FIG. 3.—Autocatalytic Working Plot of Observed Gasification Values.

appears to fit the data and the constants of Equation (2*b*) or (2*c*) are found to be:

$$k_1 = 0.00360 \qquad \frac{k_1}{k_2} = 7.31$$
$$k_2 = 0.000493$$
$$L = 630$$

A second approximation may now be made by plotting log $\frac{L_t}{L\left(G + \frac{k_1}{k_2}\right)}$

against t. For the data under consideration the constants then take the values:

$$k_1 = 0.00396 \qquad \frac{k_1}{k_2} = 8.93$$
$$k_2 = 0.000444$$
$$L = 650$$

A third, fourth or fifth approximation should follow if the change in $\frac{k_1}{k_2}$ produces a significant shift in the plotted points. In our case, the third approximation yields the values:

$$k_1 = 0.003978 \qquad \frac{k_1}{k_2} = 8.885$$
$$k_2 = 0.0004477$$
$$L = 650$$

Substitution of the numerical values of the constants in Equation (2e) and simplification yields the equation:

$$\log \frac{8.885 + G}{650 - G} = 0.1280t - 1.864$$

The agreement between the observed values of gasification and the values computed by this autocatalytic equation is shown in Table II and in Figure 2.

TABLE II

COMPARISON OF OBSERVED AND COMPUTED GAS PRODUCTION

Elapsed Time, Days	Gas Produced—Liters per Kg. Raw Volatile Solids			Difference Between Observed and Computed Values—% of Observed	
	Observed	Computed			
		Auto-catalytic	Two-stage	Auto-catalytic	Two-stage
3.71	31.3	15.5	29.6	−51	−5.4
7.96	73.6	73.3	78.0	−0.4	+6.0
11.08	156.4	165	159	+5.2	−1.7
12.96	255.5	245	244	−4.3	−4.5
15.71	392.0	376	404	−4.8	+4.1
17.67	472.0	462	480	−3.7	+1.7
19.71	535.5	532	535	−0.7	−0.1
21.88	581.0	581	577	0.0	−0.7
23.92	607.5	610	605	+0.4	−0.4
27.92	635.0	637	633	+0.3	−0.3
28.92	642.0	641	643	−0.2	+0.2
34.96	658.0	648	661	−1.5	+0.5
41.75	671.5	650	669	−3.2	−0.4

With exception of the first value, the difference between observed and computed volumes of gas production is less than 5.5 per cent of the observed value, and in over half of the cases the difference is lower than 1.5 per cent. The fact that the first value observed is about twice the computed value may be due to the seeding of the raw solids with well-digested sludge. This introduces a certain amount of gasifying material as well as the catalyzing products of previous digestion. In connection with the

latter, it may be of interest to give, for comparative purposes, the equation of a unimolecular reaction accelerated by catalytic action inherent in the original substance. In its differential form this equation is:

$$\frac{dG}{dt} = (k_1 + k_2 L_t) L_t \qquad (3a)$$

Integration places it in the following form:

$$t = \frac{1}{k_1} \log_e \frac{L(k_2 L_t + k_1)}{L_t(k_2 L + k_1)} \qquad (3b)$$

The fact that the observed limit of gasification is in the vicinity of 675 liters per kg. of raw volatile solids, whereas the corresponding computed value is 650, may be due to secondary gasification of end products of the primary digestion process as well as to the influence of seeding.

It should be noted that the numerical values of the constants of the autocatalytic equations depend upon the units of measurement employed in recording gas production.

The course of both methane production and carbon dioxide production can be formulated in the same manner as exemplified by total yield of gas.

Two-Stage Formulation.—As previously stated, the curve of gasification shows that in the range from its inception to its point of inflection the amounts of gas produced in a unit of time are on the increase, while from the point of inflection onward the amounts decrease progressively. A study of the two portions of the curve, which for convenience of reference we shall call the first and second stages of gasification, shows that the second stage is approximated closely by a unimolecular equation while the first stage can be represented satisfactorily by an equation defining a constant rate of increase.

Mathematically the first stage is characterized, therefore, by the equation:

$$\frac{dG}{G} = K'_1 dt \qquad (4a)$$

Integration and transformation to common logarithms yields the equation:

$$\log G = K_1 t + \log C_1 \qquad (4b)$$

where C_1 is the constant of integration.

This equation plots as a straight line when log G is plotted against t. This has been done in Figure 4 for the data given in Table I. The constants of the equation (K_1) and (log C_1) are given, respectively, by the slope of the line and its intercept on the ordinate at $t = 0$. It will be noted that contrary to fact, G is not 0 at $t = 0$. Since gasification may be under way when the digestion experiment is started, this situation is not too disturbing.

The second stage curve is defined mathematically by equation (1*a*), which by substituting K_2' for k' may be written:

$$\frac{dL_t}{L_t} = -K_2' dt \qquad (5a)$$

Since this stage is reached after about half the gas has been produced, integration and transformation to common logarithms must include a constant of integration C_2 as follows:

$$\log L_t = -K_2 t + \log C_2 \qquad (5b)$$

This equation, like Equation (4*b*), plots as a straight line on semi-logarithmic paper, the constants of the equation being determined in much the same

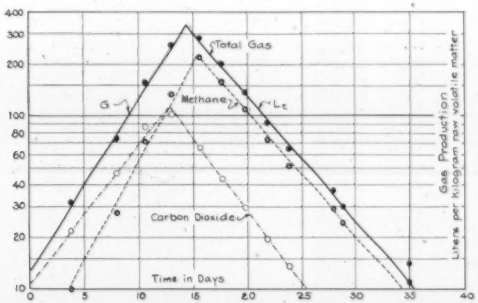

FIG. 4.—Two-Stage Working Plot of Observed Gasification Values Including Total Gas Production, Methane Production and Carbon Dioxide Production.

way. Figure 4 includes this analysis of the data in Table I. A value of $L = 672$ has been assumed.

As shown in Figure 4, the observed values fit the first-stage line well up to the point of intersection with the second-stage line, after which they adhere closely to that line. Hence both equations may be taken to become discontinuous at this point ($t = t_i$) at which gas production (G), according to this analysis, has reached half its ultimate value (L) since:

$$\log G = \log L_t = \log (L - G)$$

or

$$G = L_t = \frac{L}{2} \qquad (6)$$

Equation (2*c*) shows that at the point of inflection, gas production (G) is more accurately equal to $\frac{1}{2}\left(L - \frac{k_1}{k_2}\right)$ rather than $\frac{L}{2}$. Since in our case

$\frac{k_1}{k_2}$ is small compared with L and since the value of L for the two-stage formulation is taken to be higher than for the autocatalytic formulation, the difference is not very marked.

Because, at $t = t_t$, $\log G = \log \frac{1}{2} L_t = K_1 t_t + \log C_1$ and $\log L_t = \log \frac{1}{2} L = -K_2 t_t + \log C_2$, Equation (6) permits a restatement of Equations (4*b*) and (5*b*) as follows:

$$\log G = \log \tfrac{1}{2} L - K_1(t_t - t) \quad \text{Limits: } (t = 0) \text{ to } (t = t_t) \tag{4c}$$

$$\log L_t = \log \tfrac{1}{2} L - K_2(t - t_t) \quad \text{Limits: } (t = t_t) \text{ to } (t = \infty) \tag{5c}$$

The course of gasification, therefore, is defined by these two equations or by the four constants K_1, K_2, t_t and L. As is evident from Figure 5, how-

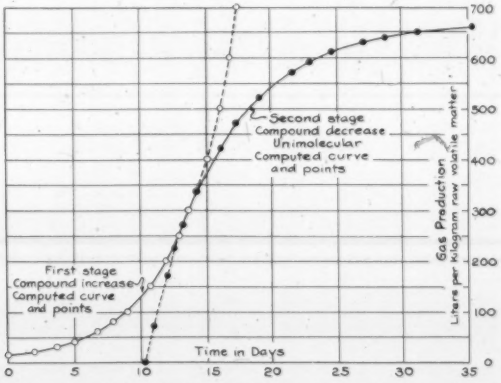

FIG. 5.—Two-Stage Plot Showing Discontinuity of the Formulation.

ever, the point $t = t_t$, $G = L_t = \frac{1}{2} L$ does not necessarily lie on the complete curve. It may lie slightly to one side, indicating a transitional stage between the two defined stages. Consideration of this transition, however, introduces refinements that are of little practical significance.

Since these equations may be written in the form:

$$\log \frac{G}{L} = -K_1(t_t - t) - 0.30103 \tag{4d}$$

$$\log \frac{L_t}{L} = -K_2(t - t_t) - 0.30103 \tag{5d}$$

it follows that the values of K_1 and K_2 are independent of the units employed in stating gas production. This is an advantage. For most purposes, the day will be found to be the most convenient unit of time, and K_1 and K_2 will then be on a daily basis.

As shown in Figure 4, the method of analysis holds equally well for total gas production, methane—or combustible gas—production and carbon dioxide production.

The equations developed for the data on total gas production presented in Table I are.

$$\log G = 1.1051 + 0.0989t \text{ (First Stage)}$$
$$\log L_t = 3.5781 - 0.0732t \text{ (Second Stage)}$$

The constants of digestion are:

$K_1 = 0.0989$
$K_2 = 0.0732$
$t_i = 14.37$ days
$L = 672$ liters per kg. of raw volatile solids

The values of C_1 and C_2 which have been displaced from Equations (4*b*) and (5*b*) by the use of Equation (6) are given by:

$$\log C_1 = \log \frac{1}{2} L - K_1 t_i$$
$$\log C_2 = \log \frac{1}{2} L + K_2 t_i$$

from which

$$C_1 = 12.74$$
$$C_2 = 3785$$

The agreement between the observed values and the computed values of gasification obtained by employing the two-stage equations is shown in Table II and Figure 2. In every case the difference between observed and computed yields is less than 6 per cent of the observed value, and in all but four instances—confined with one exception to the first stage—the difference is less than 1.7 per cent.

The point of inflection occurs at $G = 336$ liters per kg. of raw volatile matter and at $t = 14.4$ days. The corresponding values computed by the autocatalytic formulation are $G = 321$ and $t = 14.7$.

In the case under consideration the agreement between observed and computed values is better for the two stage formulation than for the autocatalytic formulation. It must be remembered, however, that two-stage formulation results from a combination of two discontinuous functions defined by four constants, while the autocatalytic formulation produces a single equation defined by three constants. The probable influence of seeding must also not be forgotten.

Although the good fit of the second-stage equation shows that this por-

tion of the process is essentially unimolecular in character, any attempt to explain this unimolecular behavior of gasifying sludge on the basis of the chemical reactions that may occur is pure speculation. A number of theoretical systems can be devised to fit the case. As previously indicated, it only becomes necessary to assume that all but one in a system of any number of reactants are present in such large amounts that the concentration of the one reactant controls. Another assumption that may well be made is that, in a mechanism consisting of a series of successive reactions, there is one of unimolecular type which is the slowest in the series and therefore the controlling reaction.

Buswell* suggests one type of digestion reaction which supports the unimolecular behavior of digesting sewage solids. He postulates that the anaerobic digestion of the organic matter takes place by the partial oxidation—by means of the oxygen of water—of the simpler organic compounds such as the fatty acids and carbohydrates. A portion of the carbon atoms of such compounds is thus oxidized to carbon dioxide; the remainder act as hydrogen acceptors, in accordance with Wieland's theory of oxidation, and yield methane. The true mechanism of this process has never been determined, but Buswell's explanation obviously satisfies the unimolecular reaction requirements: one of the reactants, water, is always present in great excess.

As pointed out by Theriault** in formulating the aerobic decomposition, or deoxygenation, of polluted waters in terms of a unimolecular reaction, it should be understood, however, that "this is simply a convenient method of representing the data, and not an expression of opinion regarding the probable nature of the reaction."

Since the unimolecular stage, or second stage of gasification, is not reached until a time t_t has elapsed during which about half of the total gas evolution has taken place, the preceding period of activity may be regarded as a preparatory period during which the processes of decomposition that result in gasification are gaining momentum at a constant rate. At time t_t they have become established, and thenceforth gasification is controlled by the fact that the gasifiable material is limited in amount and is constantly being depleted.

There is an obvious analogy between these happenings and the course of events brought about when a fixed amount of food is provided for a bacterial population capable of increasing geometrically. During the first stage the organisms—and with them the results of their activities—develop according to the law of unhindered growth represented by Equations (4). The end of this stage is reached when the remaining food supply is just sufficient to satisfy the requirements of the then existing population.

* Illinois State Water Survey, *Bulletin* **30** (1930).

** *Public Health Report*, **46**, 1302 (1931).

After this the population must die off as the food supply is used up, both decreases following a die-away curve represented by Equations (5).

Rate of Digestion.—There is another approach to the two-stage formulation of gas production which may aid those unfamiliar with the calculus.

If R_1 and R_2 equal the percentage rates of gasification, during the first and second stage, respectively, these rates being constant, the progress of digestion may be formulated as follows:

FIRST STAGE

After one day: $G_1 = C_1 + C_1 \frac{R_1}{100} = C_1 \left(1 + \frac{R_1}{100}\right)$

After two days: $G_2 = G_1 + G_1 \frac{R_1}{100} = C_1 \left(1 + \frac{R_1}{100}\right)^2$

After three days: $G_3 = G_2 + G_2 \frac{R_1}{100} = C_1 \left(1 + \frac{R_1}{100}\right)^3$

After t days: $G = C_1 \left(1 + \frac{R_1}{100}\right)^t$

This is essentially the formula for compound interest, or compound increase at a constant rate from an initial value C_1. Logarithmically:

$$\log G = t \log \left(1 + \frac{R_1}{100}\right) + \log C_1 \qquad (4d)$$

Comparison with Equation (4*b*) will show that

$$K_1 = \log \left(1 + \frac{R_1}{100}\right) \qquad (4e)$$

Since for $K_1 = 0.0989$, $R_1 = 25.6$ per cent, it follows that during the first stage the rate of increase in gasification activity is 25.6 per cent per day, the time required to reach the end of the first stage ($G = {}^1/_2 L$) depending upon the values of R_1 and C_1.

SECOND STAGE

After one day: $L_{c1} = C_2 - C_2 \frac{R_2}{100} = C_2 \left(1 - \frac{R_2}{100}\right)$

After two days: $L_{c2} = L_{c1} - L_{c1} \frac{R_2}{100} = C_2 \left(1 - \frac{R_2}{100}\right)^2$

After three days: $L_{c3} = L_{c2} - L_{c2} \frac{R_2}{100} = C_2 \left(1 - \frac{R_2}{100}\right)^3$

After t days: $L_t = C_2 \left(1 - \frac{R_2}{100}\right)^t$

This, too, is essentially the formula for compound interest, the interest being deducted, however, instead of added. Hence we deal with compound decrease at a constant rate. Logarithmically:

$$\log L_t = t \log \left(1 - \frac{R_2}{100}\right) + \log C_2 \qquad (5d)$$

Comparison with equation (5*b*) shows that

$$K_2 = \log\left(1 - \frac{R_2}{100}\right) \qquad (5e)$$

For $K_2 = 0.0732$, $R_2 = -15.5$ per cent. During the second stage of gasification, therefore, digestible matter is being gasified at a rate of 15.5 per cent per day. This does not imply, however, that the second stage—during which half of the gas is evolved—is completed in 50/15.5 = 3.2 days. It is not 15.5 per cent of the total digestible matter that is gasified each day, but 15.5 per cent of the digestible matter present at the beginning of each day.

Time of Digestion.—Since digestion, as measured by gasification, is theoretically never complete, there is no answer to the question, "What is the time of digestion?" unless we consider that for all practical purposes digestion is (technically) complete when a certain percentage, P—sometimes taken as 90 per cent—of the gas has been evolved. Both the autocatalytic equation and the two-stage formulation permit a computation of this time. If, therefore, comparisons are to be made in terms of time of digestion (P per cent complete)—rather than in terms of the constants of the formulations—Equations (2*b*) and (5*d*) can be transformed to permit calculation of this time T as follows:

$$T = \frac{2.303}{k_1 + k_2 L} \log\left(\frac{\frac{k_2}{k_1} P L + 100}{100 - P}\right) \qquad \text{Autocatalytic formulation} \qquad (2f)$$

$$T = \frac{1}{K_2} \log \frac{100}{2(100 - P)} + t_i \qquad \text{Two-stage formulation} \qquad (5f)$$

$$t_i = \frac{1}{K_1}\left(\log \tfrac{1}{2} L - \log C_i\right) \qquad (4f)$$

For the case in hand, the value of T for 90 per cent gasification is found to be 22.1 days by the autocatalytic equation and 23.9 days by the two-stage formulation. The difference is due chiefly to the discrepancy in the choice of L; this is assumed to be 650 in the autocatalytic formulation and 672 in the two-stage formulation.

Summary and Conclusions

The mathematical formulation of the course of digestion presented in this paper may be summarized as follows:

1. Gas production appears to be a satisfactory yardstick of mass activity in sludge digestion.
2. The course of cumulative gas production is an S-shaped, or ogee, curve which may be formulated mathematically.
3. Two formulations are presented:

(*a*) an autocatalytic equation, or equation of a unimolecular reaction accelerated by the catalytic action of the products of reaction;

(*b*) a two-stage formulation, or equation of a discontinuous unimolecular reaction (constant rate of decrease) preceded by a discontinuous equation of constant rate of increase.

4. The autocatalytic equation appears to interpret mathematically the kinetics of the sludge-digestion process.

5. This equation includes three constants (k_1, k_2 and L), and may be written conveniently in one of three forms as follows:

$$t = \frac{2.303}{k_1 + k_2 L} \log \frac{L(k_2 G + k_1)}{k_1 L_t} \tag{2b}$$

$$\log \frac{L_t}{L\left(G + \frac{k_1}{k_2}\right)} = \log \frac{k_2}{k_1} - 0.4343\,(k_2 L + k_1)t \tag{2e}$$

$$T = \frac{2.303}{k_1 + k_2 L} \log \left(\frac{\frac{k_2}{k_1} PL + 100}{100 - P} \right) \tag{2f}$$

The values of k_1 and k_2 are dependent upon the units of L, L_t and G as well as t.

6. The two-stage formulation is proposed for use in engineering studies because of its simplicity, directness and adequacy.

7. This formulation includes two equations defined by four constants [K_1, K_2, t_i (or C_1) and L]. The equations are discontinuous. They may be written as follows:

$$\log G = \log \tfrac{1}{2} L - K_1(t_i - t) \quad \text{Limits: } (t = 0) \text{ to } (t = t_i) \tag{4c}$$

$$\log L_t = \log \tfrac{1}{2} L - K_2(t - t_i) \quad \text{Limits: } (t = t_i) \text{ to } (t = \infty) \tag{5c}$$

$$T = \frac{1}{K_2} \log \frac{100}{2(100 - P)} + t_i \tag{5f}$$

$$t_i = \frac{1}{K_1} (\log \tfrac{1}{2} L - \log C_1) \tag{4f}$$

In conclusion the hope is expressed that mathematical formulation of sludge digestion will place experimental and operating results upon a numerical basis that is sufficiently well defined for practical purposes, and that it will aid in interpreting the course of digestion and permit evaluating in a new and more readily comparable way the influence of the various factors that affect digestion; among them: seeding, pH, temperature and stirring. Evaluation and formulation of the effects due to one or more of these factors will be the subject matter of a subsequent paper.

Gas Yield from Sewage Sludge*

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Published information from the operation of sewage treatment plants show variations in gas yields from the digestion processes of from 0.21 to 1.32 cu. ft. per capita. It is obvious that in some of the results published certain factors are not taken into consideration. Some of the more important factors are (1) low or high estimate of connected population, (2) presence of organic trade waste, (3) detention of partly digested material, (4) digestion time or storage capacity and (5) operation and control.

The gas yield is limited to the amount of volatile matter destroyed or, stating it differently, to that portion of the volatile matter content which is capable of being decomposed within a comparatively short time. A portion of the sludge which is lost on ignition is very resistant to anaerobic decomposition. This is evidenced by some long-time digestion experiments carried on in the laboratory. During the first six months of incubation the volatile matter was reduced by 54.0 per cent, while during the following year the volatile matter reduction amounted only to an additional 13.4 per cent. Another long-time experiment showed that volatile matter reduction in $5^1/_2$ years amounted to 72.3 per cent. Within reasonable time, volatile matter reduction rarely exceeds 70 per cent under most carefully controlled conditions. Some of the volatile substances, however, decompose very rapidly, notably some fatty substances and certain cellulosic compounds.

It is also a fact that some of the fats and oils produce more gas than others, with the result that not only the quantity but also the type of waste affects the gas yield. This is particularly true when certain types of trade wastes are received which are capable of rapidly yielding large quantities of gas. It appears also that the destruction of some wastes exerts an influence upon the decomposition of organic compounds which ordinarily require considerable time for complete destruction. This "stimulation" effect results in more rapid digestion and relatively greater gas yields. Other wastes however, depress, hamper or retard decomposition of organic compounds, with the opposite result.

On the one side there are enthusiasts who claim excessive gas yields, which when checked up, are sometimes more by weight than the total quantities of solids or volatile matter received, while other observers set their claims so low that it appears to be hardly worth while to collect the gas and to utilize it around the plant. Somewhere between those extremes is the actual fact.

* *Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Sewage Research.*

In an attempt to gage the possible gas yields from sewage solids the following experiments are recorded. The question of where most of the gas comes from was considered mainly in relation to other work, where the effect of certain wastes upon digestion and gas production has been studied.

Methods

Fresh solids were incubated at 75° and 85° F. A portion incubated at 75° F. was treated with hydrated lime to control the reaction. No seed

TABLE I

COMPOSITION OF SLUDGE AT BEGINNING AND END

Days	pH	Solids, %	Ash, %	Total Carbon, %	Total Nitrogen, %	Ether Extract (Fats), %	Cellulose %	Carbonates P. p. m.	B. O. D. 24 Hr., P. p. m.
				No. 65, Incubated at 75° F.					
0	5.5	5.69	20.8	44.3	2.46	54.2	1.88	350	...
203	7.1	2.61	42.5	29.4	2.04	18.4	0.0835	950	641
				No. 66, Incubated at 75° F. (Limed*)					
0	5.5**	5.88	22.4	42.5	2.59	56.1	1.87	350	...
203	7.5	2.67	48.5	25.7	2.21	16.7	0.0133	1450	820
				No. 67, Incubated at 85° F.					
0	5.5	5.71	20.7	44.6	2.45	54.4	2.19	350	...
203	7.2	2.39	40.4	26.8	2.29	16.3	0.0147	1150	693

NOTE: Ash, carbon, nitrogen, fats on basis of solids.

* Lime added per liter sludge 1.38 gr.

** pH raised to 7.5.

TABLE II

MATERIALS DESTROYED DURING DIGESTION

Vol. No.	Matter Red. Gr.	Matter Red. %	Total C in Vol. Matter Gr. Begin	Total C in Vol. Matter Gr. End	Total C in Vol. Matter % Red.	Ether Soluble (Fats) Gr. Begin	Ether Soluble (Fats) Gr. End	Ether Soluble (Fats) % Red.	Total Nitrogen Loss Gr.	Total Nitrogen Loss %	Cellulose Loss Gr.	Cellulose Loss %
65	45.0	66.7	37.57	11.53	69.1	46.2	7.2	84.4	0.61	17.0	1.65	98.1
66	47.9	70.0	37.60	10.28	72.6	49.2	6.7	86.5	0.57	14.7	1.64	99.7
67	47.3	68.4	38.25	9.62	75.1	46.6	5.9	87.4	0.24	6.5	1.87	99.8

material was used, to avoid complications of calculations and the possibility that small quantities of gas may be produced from the seed material. The fresh solids were analyzed at the beginning and end of the experiment and the pH values determined at frequent intervals. All gas was collected over gas-saturated water and analyzed whenever the containers were full.

Results

The quantity of solids used for each batch was 1500 cc. and the total gas produced varied from 50.8 to 64 liters. The composition of the sludge at the beginning and end of the experiment is given in Table I. The reduc-

tion in volatile matter, carbon, fats, nitrogen and cellulose is shown in Table II. The percentage reduction of volatile matter after 203 days of incubation was high in comparison with results obtained from digestion experiments in which shorter incubation periods were used. It may be

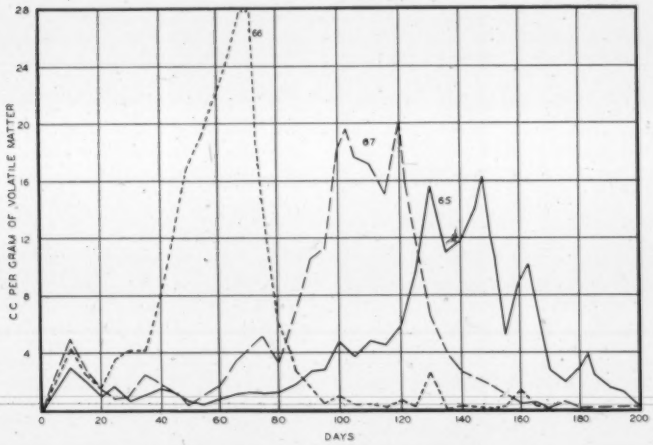

FIG. 1.—Daily Gas Production per Gram Volatile Matter.

assumed, therefore, that practically all gas that could be produced in a reasonable length of time was given off. The 24-hour B. O. D. of the final residue was lower than ordinarily may be expected from material subjected to digestion for a shorter time. A study of Table II shows that

TABLE III

TOTAL GAS AND COMBUSTIBLE GAS PRODUCTION

	Per Gram Vol. Matter Present			Per Gram Vol. Matter Destroyed		
No.	Total Gas, Cc.	Total CO_2, Cc.	Combustible, Cc.	Total Gas, Cc.	CO_2, Cc.	Combustible, Cc.
65	754	142	530	1140	214	800
66	905	167	622	1320	243	906
67	941	168	625	1360	246	896

cellulosic material, as determined by the method used, which indicates the easily decomposable portion of the cellulose rather than materials like lignins, disappeared almost completely. From 84.4 to 87.4 per cent of the ether-soluble material was destroyed and the total carbon was reduced

68.1 to 75.1 per cent. There was also a small but absolute loss of nitrogen, although the relative destruction was much less than of the other components, as indicated by the higher percentage of nitrogen in the residue. A portion of the total carbon remained in the liquid as shown by the increase in carbonates. The carbonates present in the liquid are included in the total carbon determinations.

The total quantities of gas, the quantities of combustibles and CO_2 produced per gram of volatile matter originally present, and the amounts produced per gram of volatile matter destroyed are given in Table III. The total gas varied from 1140 to 1360 cc. per gram of volatile matter destroyed. Somewhat similar variations occurred in the amounts of CO_2 and combustible gas produced. Gas production of the material incubated at 75° F. was complete after 200 days, while the same material incubated at the same temperature, but controlled accurately with lime, stopped gasifying for all practical purposes after 95 days. The material incubated at 85° F. required 160 days for completion. It should be remembered that the materials had not been seeded.

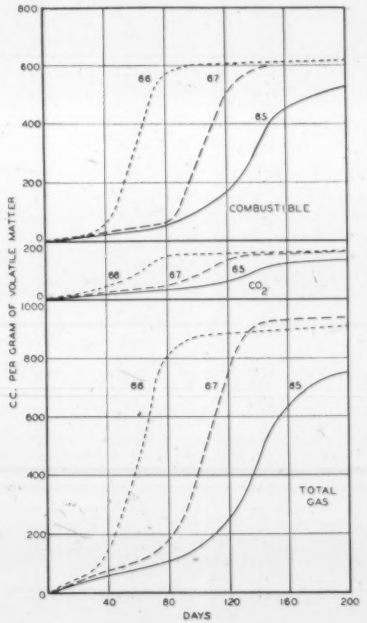

FIG. 2.—Total Gas, Combustible and CO_2 per Gram Volatile Matter Originally Present.

The daily fluctuations in gas production of the three batches of material are shown in Figure 1. The cumulative total gas, CO_2, and combustible gas production per gram of volatile matter originally present are shown in Figure 2. The quantity of gas produced per gram of volatile matter destroyed from the material incubated at 75° F. was about 13 to 16 per cent less than from the limed material and also that incubated at 85° F. The difference in percentage of combustible gas was slightly lower, namely, 10 to 11 per cent. A part of the difference in total gas production could be

attributed to the digestion time, which was the same in days in all tests but relatively longer for the limed material and the material incubated at 85° F. because there was some gas produced after the materials could be considered digested. It took the material incubated at 75° F. 203 days to produce 754 cc. of gas per gram of volatile matter, whereas the limed material required 70 days and the material incubated at the higher temperature 120

TABLE IV

GAS ANALYSES

No. Days	65 CO_2, %	65 CH_4, %	66 CO_2, %	66 CH_4, %	67 CO_2, %	67 CH_4, %
6	21.1	0	22.0	0	25.9	0
15	41.8	35.2	41.1	41.8	45.1	37.6
31	..	..	27.0	68.0	..	..
39	..	..	20.2	73.0	..	..
44	35.9	54.5	18.4	77.0	..	..
46	..	..	18.2	78.3	..	..
49	..	..	17.6	71.6	..	..
51	..	..	16.3	77.7	..	..
56	..	..	14.7	76.9	16.0	54.4
62	..	..	17.8	77.3	..	..
66	..	..	19.1	73.5	..	..
71	21.6	64.5	18.7	71.2	16.7	54.5
78	..	..	18.2	77.5	18.3	76.7
86	..	..	..	..	17.7	76.2
89	..	..	..	..	17.6	77.4
94	19.2	75.1	..	..	16.2	79.1
97	15.6	76.8	..	..	16.3	78.8
103	..	..	..	..	17.7	75.5
106	17.0	76.4	..	..	..	..
109	..	..	..	..	17.2	77.0
115	16.8	77.2	..	..	16.5	75.0
122	16.6	79.2	..	..	19.7	75.0
127	18.8	76.0	..	..	18.3	77.4
136	15.7	74.7	..	..	..	..
146	17.6	74.9	..	..	..	..
157	15.6	70.6	..	..	15.4	64.8
176	18.1	70.8	..	..	..	..
204	18.1	70.8	17.3	54.7	10.5	77.4

days to produce the same quantity. However, the fact that actually 10 to 11 per cent more gas per gram volatile matter destroyed was produced in tests 66 and 67 would indicate that certain substances were destroyed to a greater extent in the latter tests. The results in Table II show that there was actually a somewhat greater destruction of fats and cellulose in tests 66 and 67. The loss in nitrogen, however, was somewhat less, the differences amounting only to a fraction of one gram.

The composition of the gas produced during digestion is given in Table

IV. For comparison, cumulative gas production from the differently treated materials, together with the CO_2 and combustible gas produced are shown in Figure 2. The composition of the gases was slightly different at the higher temperature and from the material treated with lime, as compared with the material incubated at 75° F.

Discussion

The incubated materials were kept sufficiently long to produce for all practical purposes the greatest possible yield. The ultimate yield of gas would undoubtedly have been higher, but, in practice, only in rare cases would a volatile matter reduction of more than 67–70 per cent be encountered. Greater destruction would depend entirely upon the time of incubation, since factors like temperature, reaction, etc., play less and less important rôles when destruction of volatile matter has progressed so far. The fact that the same material at a higher temperature produced equal quantities of gas in 60 per cent of the time and when properly limed in about 35 per cent of the time of the uncontrolled test, shows the importance of operation and control.

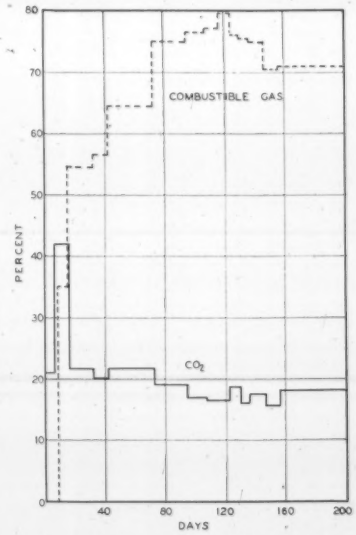

FIG. 3.—Variations in CO_2 and Combustible Gas Production of Material at 75° F.

There was a difference in the total quantities of gas produced from the materials treated differently. The composition of the gas in the three tests was also slightly different, as can be seen from the summary in Table V, where the average composition of the gas produced is given and the B. t. u. values. A persual of Table IV shows that the composition of the gases varies considerably during the course of digestion. To illustrate this more clearly the percentages of CO_2 and combustible gas are graphically compared for one of the materials incubated at 75° F. (Figure 3) The percentage of combustible gas increased persistently until gasification became most vigorous (after 120 days), while during the peak of gas produc-

tion the percentage of combustible gas decreased from nearly 80 per cent to a little over 70, with an average of about 75 per cent.

TABLE V

SOLIDS REDUCTION AND AVERAGE COMPOSITION OF GAS

No.	Temp., ° F.	Reduction, %	Solids CO_2, %	Combustible, %	B. t. u.
65	75	53.0	18.9	70.0	700
66	75*	54.6	19.4	68.8	680
67	85	58.2	17.8	66.3	665

* Lime added.

TABLE VI

VOLATILE MATTER DESTROYED AND WEIGHT OF GAS PRODUCED (AT 20° C. AND 760 MM. PRESSURE)

(CO_2—1.79, CH_4—0.67 Gm. per Liter)

No.	Vol. Matter Destroyed, Gm.	Weight of CO_2, Gm.	Weight of CH_4, Gm.	Total Weight of Gas, Gm.
65	45.0	17.15	24.0	41.15
66	47.9	20.0	28.4	48.5
67	47.3	20.4	28.4	48.8

Total gas production varied from 1140 to 1360 cc. per gram volatile matter destroyed (Table III). The weight of the gas (depending upon the composition, calculated from the quantities of CO_2 and combustible gas produced), compared with the amount of volatile matter destroyed, would indicate whether all volatile matter was actually converted into gas. For comparative purposes it is assumed that all the gas consisted of the recorded percentage of CO_2 and that the combustible gas produced was methane. This is probably incorrect, because upon analyses small quantities of hydrogen may be found at the beginning of digestion; from 0 to 3 per cent of carbon monoxide is found on occasion and small quantities of other combustible gases than hydrogen and methane.

The calculated results obtained are given in Table VI. Considering the possible errors which may enter, especially in the determination of volatile matter content and also in the number of gas analyses made, the results check very well. The fractions of a gram of nitrogen lost do not alter the picture. In the cases of tests 66 and 67 all volatile matter destroyed is accounted for in the gas (assumed composition based upon analyses), while in the case of number 65, over 91 per cent of the volatile matter is accounted for. The somewhat greater calculated weight of the gas for tests 66 and 67 is probably due to the errors mentioned above and a slightly different composition of the gas recorded.

In regard to the question as to which component of the sludge produces

the most gas, we naturally turn to the constituent most abundant, namely, ether-soluble material. The ether extract (fats) constituted from 54 to 56 per cent of the total solids. Volatile matter reduction amounted to 68 to 70 per cent, while reduction of fats reached percentages of 84 to 87, so that of the total volatile matter reduction of about 87 per cent could be accounted for by the destruction of fats. Comparing the amounts of total carbon lost with the quantities of carbon recovered in the gas and the amount of fats destroyed (Table VII) it appears that more than 75 per cent of the gas can be accounted for, even if we assume that the total carbon in the fatty substances decomposed amounted to only 50 per cent of its total weight. It is evident, therefore, that other carbonaceous substances produced only a relatively small quantity of the total gas.

TABLE VII

REDUCTION IN CARBON IN SOLIDS AND CARBON RECOVERED IN GAS

No.	C Lost, Gm.	C in CO_2, Gm.	C in CH_4, Gm.	C in Total Gas, Gm.	Red. Fats, Gm.	C in Fats (Assumed 50%), Gm.
65	26.27	4.78	17.21	21.99	39.0	19.5
66	26.32	5.74	21.40	27.14	42.5	21.2
67	28.63	5.76	21.45	27.21	40.7	20.3

Data obtained by us in about twelve towns in the same district show that the daily per capita production of suspended solids varied from 42 to 90 grams. In some of these towns industries are located and in others not. Records from the Plainfield sewage disposal plant show that the daily per capita production of suspended solids amounts to 64 grams. Records from widely scattered places indicate that suspended solids in domestic sewage average about 70 grams per capita, but as soon as trade wastes are present the so-called per capita production increases, sometimes to as high as 200 grams per capita daily. It appears that a production of 70 grams suspended solids per capita, with an ash content of 20 to 25 per cent, may be used for calculating the ultimate quantity of gas produced. If such weight of solids is removed and thoroughly digested, so that 70 per cent reduction of volatile matter takes place, the maximum amount of gas would be from 1.77 to 1.88 cu. ft. per capita. This maximum yield is in practice not possible, because even if the clarified effluent is further treated by the activated-sludge process, a portion of the suspended solids is lost in the oxidation processes and some of the easily oxidizable materials, which are capable of producing gas, are lost into the air. The latter fact is well illustrated by the lower gas yields obtained from digesting activated sludge.

In modern practice the percentage of suspended solids retained in the settling devices is usually from 50 to 60 per cent. These retained solids are quickly transported to the digesters. In cases where the solids are re-

tained for comparative long periods (one to two weeks or more) disintegration takes place and a portion of the solids capable of producing gas enter the supernatant liquid or are washed out with the effluent. Assuming again that 70 per cent of the volatile matter is destroyed, the total quantity of gas produced when 50 per cent of the suspended solids were retained would be from 0.89 to 0.94 cu. ft. per capita and with 60 per cent suspended solids retained 1.06 to 1.13 cu. ft.

Ordinarily a destruction of volatile matter amounting to 50 per cent is very good in practice. The time required to accomplish this varies from 30 to 90 days, depending upon operation and control (temperature, seeding, reaction, etc.). With such a percentage volatile matter destruction of the 50 to 60 per cent suspended solids retained, the possible quantity of gas produced would be from 0.61 to 0.756 cu. ft. per capita. Some of the results published, where sufficient data are available to calculate the percentage destruction of volatile matter, in addition to the quantity of suspended solids retained, come rather near to the above figures. Others, however, are substantially higher. In the latter cases either the quantities of sludge received are materially higher due to organic trade wastes, or the connected population is erroneously estimated.

Calculations on the basis of pounds of volatile matter retained with a destruction of 50 per cent during digestion, show that the gas produced would amount to 10.8 cu. ft. per lb. of volatile matter retained. The quantities of gas reported in the literature, based upon the pounds of volatile matter retained as settled sludge, vary in unheated tanks from 4.5 cu. ft. to 7.5 cu. ft. This highest figure, at Essen-Frohnhausen (*Gesundh.-Ing.*, **54,** 736 (1931)), is the average for 3 years (1928–1931) with a temperature of 16.5° C. For heated tanks the variations run from 7.7 to 11.52 cu. ft. per pound volatile matter. According to balance sheets of Mr. W. S. Stanley, gas production at San Antonio, Texas, with tanks heated to 94–104° F. amounted to slightly less than 2 cu. ft. per pound of dry solids over a period of 4 months after the plant had been in operation for some time. The digesters are overloaded so that no complete digestion occurs. Several other sets of results are available where the gas production is abnormally low, but these can be explained on the basis of inadequate digestion capacity or difficulties encountered. On the other hand, the high gas yields reported, both per capita and per pound of volatile matter, can probably be traced to inadequate information on the population connected, insufficient analyses and the presence of organic trade wastes which have not been taken into consideration. Gas production from domestic sewage solids of from 0.60 to 0.75 cu. ft. per capita per day or 8.0 to 11.5 cu. ft. per pound of total volatile matter, when heated tanks are used with proper operation and control, appear to be all that should be expected under practical conditions.

Summary

The gas yield from domestic sewage sludge to be expected under practical conditions, with proper control and good operation, will probably vary from 0.60 to 0.75 cu. ft. per capita per day. Larger yields may be due to excessive digestion capacity (time of digestion and storage extended) and the presence of organic trade wastes. It is unlikely that gas production from settled sludge will be greater than from 0.9 to 1.1 cu. ft. per capita even under conditions of prolonged digestion. On the basis of pounds of volatile matter retained, maximum gas yields to be expected would be from 8.0 to 11.5 cu. ft.

In laboratory experiments at least 75 per cent of the gas yield could be accounted for by the destruction of fats (ether extract). Nearly all cellulosic material capable of decomposition was destroyed and some nitrogen lost.

The Relation Between the Chemical Composition of Organic Matter and the Quality and Quantity of Gas Produced During Sludge Digestion

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On the basis of published material and sewage plant reports there seem to be differences of opinion as to the amount of gas that can be recovered per pound of organic matter decomposed under anaerobic conditions. A considerable variation can be attributed to sampling and analytical errors. Certain analytical errors, the chief ones of which are the loss of ammonium compounds, volatile acids and free and dissolved carbon dioxide at the temperature of the determination of total solids, and the inability to get representative digested sludge samples, are difficult to overcome. The correct volume of pumped sludge is also hard to determine at times. These and other errors involved in determining solids have been discussed elsewhere.[4,5,13] Too high ashing temperatures (above 800° C.) also give misleading data.

There are theoretical limits within which gas data must fall. A discussion of the research justifying this statement, with a consideration of the relation between the chemical composition of the material being decomposed and the quality (methane content) and quantity of gas produced, constitutes the subject matter of this paper.

The mechanism of the aerobic and facultative biological degradation of mixed and pure chemical substances is fairly well understood.[16] Studies on the mechanism of the anaerobic degradation of materials to CO_2 and CH_4 have not been so fruitful. Most of these latter studies[1] have been on fermentations where only a moderate amount of the material fermented has been recovered as easily separated and accurately determined end products.

Some few years ago Buswell and co-workers attacked the problem and have been able to obtain practically 100 per cent fermentation of many pure materials to CO_2 and CH_4, thereby making it possible to establish the simple over-all equation representing the degradation of the material in question. This in turn has made it possible to establish the quality, that is CH_4 content, weight and volume of gas that can be expected as end products in the degradation of pure and mixed chemical substances.

One might have expected the complete anaerobic fermentation of cellulose, fats, fatty acids, sugars, etc., to have been brought about by the bacteria through inter- or intramolecular oxidation-reductions. It would seem, however, that all of these fermentations may be most simply represented as the result of hydrolysis. The formation of intermediate

products undoubtedly involves the other two types of action. F. H. Hesselink van Suchtelen[19] recently endeavored to draw a relation between the specific gravity and thermal value of materials and their expected mode of decomposition. His theory is based entirely on intramolecular oxidations. He offered no experimental proof for his ideas.

Boruff and Buswell[3] have shown that the polysaccharides, such as starch, cellulose, the pentosans and cellulosic materials, decompose to give a gas composed of equal volumes of CO_2 and CH_4 (corrected for CO_2 retained in fermentation flask). Cellulose was found to decompose quantitatively as follows:

$$\begin{array}{rcl} (C_6H_{10}O_5) + H_2O & = & 3CO_2 + 3CH_4 \\ 162 + 18 & = & 180 \end{array} \qquad (1)$$

Studies have also been made on the anaerobic fermentation of casein and peptone.* The casein and peptone used had over-all empirical formulas of $C_{148}H_{233}O_{48}N_{37}S$ and $C_{124}H_{250}O_{46}N_{43}S$, respectively, and decomposed as follows:

$$4C_{148}H_{233}O_{48}N_{37}S + 524H_2O = 136CO_2 + 308CH_4 + 148NH_4HCO_3 + 4H_2S \qquad (2)$$

$$8C_{124}H_{250}O_{46}N_{43}S + 914H_2O = 125CO_2 + 394CH_4 + 344NH_4HCO_3 + 8H_2S \qquad (3)$$

Neave and Buswell[12] have studied the anaerobic decomposition of the various nitrogenous constituents of sewage as well as the fatty acids. They have shown that the latter decompose to give CO_2 to CH_4 ratios which increase with the molecular weight of the acid. The following two examples and formulae will serve to illustrate:

n-Butyric acid

$$\begin{array}{rcl} 2C_4H_8O_2 + 2H_2O & = & 3CO_2 + 5CH_4 \\ 176 + 36 & = & 212 \end{array} \qquad (4)$$

Stearic acid

$$\begin{array}{rcl} C_{18}H_{36}O_2 + 8H_2O & = & 5CO_2 + 13CH_4 \\ 284 + 144 & = & 428 \end{array} \qquad (5)$$

Fatty acid formula

$$C_nH_{2n}O_2 + \frac{(n-2)}{2} H_2O = \frac{(n+2)}{4} CO_2 + \frac{(3n-2)}{4} CH_4 \qquad (6)$$

Symons and Buswell[17] have studied in a similar manner the anaerobic fermentation of carbohydrates, ketones, aldehydes, alcohols, glycols, acids, esters and other related compounds. All of these substances hydrolyze anaerobically to give definite volumes and ratios of CO_2 and CH_4. Tarvin and Buswell[18] found that even benzoic acid would decompose as follows:

$$\begin{array}{rcl} 4C_6H_5COOH + 18H_2O & = & 13CO_2 + 15CH_4 \\ 488 + 324 & = & 812 \end{array} \qquad (7)$$

* Peptone data by Buswell and Thrush (unpublished).

All of these fermentations are exothermic and answer the thermodynamic requirements of biological reactions. The most significant and interesting fact is that such a great variety of substances should ferment to give practically quantitative yields (90 to 100%) of CO_2 and CH_4 in such ratios as can be represented by simple hydrolysis equations. Examples of recovery data are given in Table I.

TABLE I

ANAEROBIC FERMENTATION OF PURE SUBSTANCES, 25–35° C.

Substance Fed	Grams Fed	CH_4 as Drawn %[1]	Gas Recovered, S. T. P.[2] Vol., Liters	Weight,[4] Gms.	Ratio CO_2:CH_4	Theoretical Ratio[3] CO_2:CH_4	Per Cent of Material Fed Recovered as $CO_2 + CH_4$[3] Found	Theoretical
Cellulose[a]	180.0	48–55	152.30	197.99	1:1.03	1:1.00	111	111
Starch[a]	68.5	48–55	56.71	74.86	1:1.0	1:1.00	109	111
Glycerol[b]	10.0	56–60	7.11	8.81	5:7.07	5:7.00	88	90
Acetic acid[c]	114.18	48–55	80.80	107.41	1:0.97	1:1.00	94	100
Propionic acid[c]	130.06	56–60	119.70	145.15	5:6.93	5:7.00	112	112
Butyric acid[d]	150.0	60–65	158.46	184.82	1:1.70	1:1.67	123	120
Benzoic acid[d]	91.38	55–60	103.27	144.0	1:1.20	1:1.16	158	166
Casein[e]	47.5	65–72	44.50	57.8	1:1.08	1:1.07	...	171[5]
					1:2.30[1]	1:2.26[1]	76[1]	82[1]
Peptone[e]	27.5	62–72	25.56	26.21	1:0.6	1:0.8	...	166[5]
					1:2.6[1]	1:3.2[1]	48[1]	46[1]
Carbon (theoretical)	1.0		1.87	2.5		1:1		250

[1] Gas as drawn, N_2 free basis but not corrected for retained CO_2.
[2] Corrected for dissolved CO_2.
[3] Based on equations given in body of article.
[4] Does not include small volume of N_2 (*Ind. Eng. Chem.*, **18**, 407 (1926)).
[5] Includes $NH_4HCO_3 + H_2S$.
[a] Boruff
[b] Symons
[c] Neave All with Buswell.
[d] Tarvin
[e] Thrush

Summarizing the research data given here, as well as other data to be published soon, one notes that the lower the oxygen in relation to the carbon and hydrogen content of the material, or in other words, the lower the degree of oxidation, the greater will be the methane-content of the gas produced during anaerobic fermentation. The volume and weight of gas produced also depends on the composition of the material being decomposed. *The weight of the gas recovered, when corrected for the CO_2 retained in the fermentation tank, is greater than the weight of the material decomposed, by the amount of water which has entered the reaction.* Reference to Table I and to the equations given will illustrate this fact. In the few cases where water is not added during the fermentation, as, for example, in the fermentation of acetic acid, or where it is actually withdrawn from the

substrate, as, for example, in the fermentation of formic acid and glycero[1], the weight of the gas is, respectively, equal to and less than the weight of material decomposed.[12] The greatest possible weight and volume of gas that could be recovered would be from pure carbon, which theoretically should decompose as follows:

$$2C + 2H_2O = CH_4 + CO_2$$
$$24 + 36 = 60$$

This maximum limit amounts to 1867 cc. or 2.5 g. of gas per gram of carbon decomposed (30 cu. ft. per lb. decomposed). Greater gas yields than this have been reported but they are in error.

The complete decomposition of fats (glycerol esters of fatty acids) gives, in accordance with their molecular weight, a gas of a CH_4 content of from 62 per cent, for glycerol tributyrate, to 72 per cent, for glycerol tristearate, and should produce from 1112 cc. (1.33 grams) to 1433 cc. (1.54 g.) of

TABLE II

GAS PRODUCTION FROM VARIOUS SEWAGE CONSTITUENTS

Gas as Drawn (Not Corrected for Retained CO_2) 760 Mm. and 0° C.

Material	CH_4, %	Volume per Gram Decomposed, Cc.	Weight per Gram Decomposed, Gm.	Volume per Lb. Decomposed, Cu. Ft.
Fats	62–72	1112–1433	1.33–1.54	18–23
Scum[8]	70–75	900–1000***	...	14–16
Grease*	68	1050	1.13	17
Crude fibre	45–50	892	1.11	13
Protein**	73	720	0.76	12

* Petroleum ether extract, fats, lime soaps, etc. Reference 11 and 12.

** Average composition, Mathew's "Physiological Chemistry," 4th Ed., p. 116.

*** Per gram of scum added.

gas per gram of fat fermented (18 to 23 cu. ft. per lb. digested). Neave and Buswell[11,12] found that a gram of extracted sewage "grease," which was composed of approximately a 50–50 mixture of lime soaps and unsaponified grease, gave 1050 cc. of gas containing 67.7 per cent CH_4 (17 cu. ft. per lb. added). Keefer and Kratz[8] likewise noted that primary settling tank scum, which was composed largely of "grease," would form from 900 to 1000 cc. of gas per gram of fresh dry volatile solids (14 to 16 cu. ft. per lb. added). The gas contained from 70 to 75 per cent CH_4. As pointed out previously, the greases and soaps furnish the best quality and the greatest quantity of gas.[4,12]

Starch, cellulose, hemicelluloses and that part of crude fiber that decomposes, give, per gram, 892 cc. or 1.11 g. of gas of a CH_4 content of 50 per cent (13 cu. ft. per lb. digested). Protein materials, depending on their specific chemical composition, give, per gram, from 650–750 cc. or about 0.7 g. of gas of from 65 to 75 per cent CH_4 (10 to 12 cu. ft. per lb. decomposed). The CH_4 content here is high due to the retention of much

of the CO_2 in the liquor as the ammonium salt. The above data are summarized in Table II.

Due to the fact that CO_2, free and combined as ammonium and alkaline earth carbonates, is lost in the overflow and sludge liquors drawn from digestion tanks, the actual recovery of gas per pound of volatile matter decomposed may be slightly lower than certain of the data given above. For this same reason the CH_4 content of the gas as drawn may be a little greater. This is largely overcome, however, by the diluting effect of the dissolved N_2 which enters the digester.[6] In this connection, it is interesting to note that in the digestion of the casein reported in Table I, 1.97 g. of total nitrogen were added in the inoculum and 7.40 as casein nitrogen, making a total of 9.37 g. Of this, 9.59 g. were recovered, thus making it impossible to account for the small amount of N_2 found in the gas from any source other than the air. The small amount of H_2 noted in the researches herein reported (0.1 to 1.0%), as well as that amount noted in normally operating digestion tanks, is too small to have much bearing on the subject. So far no definite data have been secured as to the source of this gas. Liming of digestion tanks increases the CH_4 content of the gas in proportion to the lime added. Sour[13] and foaming[7] tanks produce less CH_4 and greater percentages of CO_2 than normally operating tanks. Digestion of solids under thermophilic conditions (55° C., 131° F.) produces no noticeable effect on the quality or quantity of gas produced in normally operating tanks. Rudolfs[14] has noted but little difference.

The above considerations as applied to sludge digestion are based on the assumption that that portion of the raw materials which is left is unaltered or is essentially of the same over-all composition (ratio of C:H:O:N) as the original material. On the basis of such data as are available, this seems to be a valid assumption.[2,3,10,12]

These considerations account for the fact that in certain sewage studies Buswell and Pearson[4] found that in the digestion of 2116 pounds of volatile matter, of which 1465 were grease and 516 pounds protein, they obtained 10.3 cu. ft. of gas, containing 63.4 per cent CH_4, per pound of volatile matter added. This amounts to a gas production of 18.1 cu. ft. or 1.25 pounds of gas per pound of volatile matter decomposed. The raw solids added and the overflow liquors and sludges withdrawn, respectively, in this study, were drawn into open tanks where they were accurately measured and sampled. Figures furnished by Sperry[15] show that at the Aurora, Illinois, plant they are recovering 11.2 cu. ft. of gas per pound of volatile matter added which amounts to 19.3 cu. ft. or 1.26 pounds of gas per pound of volatile matter decomposed. These data are based on accurate raw sludge figures and digester balances arrived at through monthly tank soundings and solids computations. All gas data have been reduced to 0° C. and 760 mm. pressure. Analytical data furnished by Larson[9] of

the Springfield, Illinois, Sanitary District show for the year of 1931 a gas production of 12.0 cu. ft. of gas per pound of volatile solids added and 17.4 cu. ft. or 1.15 pounds of gas per pound of volatile matter digested. Calculations made on the basis of Rumsey's[20] annual report for the Grand Rapids, Michigan, plant show that they recovered 9.8 cu. ft. of gas per pound of volatile matter added and 18.1 cu. ft. or 1.22 pounds of gas per pound of volatile matter digested. In no case were data furnished by plants which showed the recovery of less than a pound of gas per pound of volatile matter digested.

TABLE III
SEWAGE GAS RECOVERY DATA

Author	CH_4 in Gas, %	Gas Recovered per Lb. Volatile Matter[3] Added Volume[2], Cu. Ft.	Digested Volume, Cu. Ft.	Weight,[1] Lb.	Nature of Solids
Buswell and Pearson[4]	63	10.3	18.1	1.25	Fresh plus Nidus tank sludge
Sperry[15]	61	11.2	19.3	1.26	Fresh sludge
Larson[9]	66	12.0	17.4	1.15	Fresh plus activated sludge
Rumsey[20]	66	9.8	18.1	1.22	Fresh sludge

[1] Does not include weight of N_2.
[2] Variation in figures due to type of solids and time of digestion.
[3] All gas volumes reduced to 760 mm. and 0° C. Volume as drawn about 10% greater.

Summary

The above research data show that the methane content, as well as the total gas produced in the anaerobic decomposition of organic matter, depends on the ratio of C:H:O:N in the material being decomposed. The quantitative data all indicate that water acts as the oxidizing-reducing agent.

Of the various sewage constituents, the greases, fats and soaps furnish the best quality (62–75 per cent CH_4) and greatest quantity of gas. Protein materials furnish a similar high grade of gas but in lesser amounts per pound digested. The small amount of cellulose and cellulosic materials that digests furnishes a gas of only 45–50 per cent methane. With but a few exceptions all organic materials, when fermented anaerobically, gives more than a pound of gas per pound of volatile matter digested.

Large scale sewage plant data check well with the results of laboratory studies.

The above considerations emphasize the advisability of digesting all greases if mechanically possible. They also emphasize the error in considering the weight of gas produced as a direct measure of the weight of volatile matter digested and hence of digestion efficiency. The weight of gas at 0° C. and 760 mm. pressure divided by 1.2 would seem to give a more logical figure.

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The Activated-Sludge Process at Salinas, California, with Particular Reference to Causes and Control of Bulking

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The activated-sludge process has been in use at Salinas, California, for less than two years (Figure 1). The plant is small and would not be of particular interest except for the difficulties encountered in its operation. During the brief operation period bulking, short circuiting, poor clarification and loss of nitrification have been experienced at times, while on other occasions a very satisfactory effluent has been produced. A great deal of experimental work has been done in an effort to eliminate these various difficulties. The plant has been operated with and without sludge reaeration, with and without baffling the aerators and with varying amounts of sludge and air. All experiments have been subject to fairly complete laboratory control. As a result of these experiences the conclusion has been drawn that the primary cause of most of the difficulties encountered in the activated-sludge process is the upsetting of the balance between adsorption and biological oxidation within the sludge.

In this paper the design and operation of the plant will first be described, and then an attempt will be made to show how the adsorption-oxidation balance may be determined and controlled and how variations in that balance affect the results obtained by the activated-sludge process. Although the paper is based, primarily, upon Salinas conditions and experiences, the current literature has been freely consulted. It is hoped that some of the conclusions drawn will be found to be of sufficient general application to be of material value to the operators of other "difficult" plants.

Character of the Sewage

The population of Salinas is subject to considerable seasonal variation, being higher in the summer than in the winter. The average is about 10,000. The ground-water level is also subject to considerable variation. These two factors combine to give a peak flow of about 720,000 gal. per day in July and a minimum of 520,000 gal. per day in November. On wet years there may be a winter peak approaching, or even exceeding, the summer peak. The average flow is about 620,000 gal. per day.

The sewage, although chiefly domestic in origin, is very strong and contains considerable grease. As might be expected, its strength varies considerably, being greatest in November and least in March. Average monthly figures for suspended solids and ammonia nitrogen will range

from 260 to 450 p. p. m. and from 25 to 45 p. p. m., respectively. The high grease content, which is not subject to so much seasonal variation, is augmented by frequent discharges of kerosene and lubricating oil. Efforts to eliminate this difficulty, made with the coöperation of the police department, have not been very successful.

The sewage reaches the plant in a fairly fresh condition although occasionally as much as 2.0 p. p. m. of hydrogen sulphide is detectable upon arrival. Table I contains a typical analysis of the crude sewage.

Plant Description

The Salinas plant combines separate sludge digestion with the activated-sludge process. The crude sewage, after passing through a bar screen, is pumped to a primary settler having a theoretical detention period of 1.4

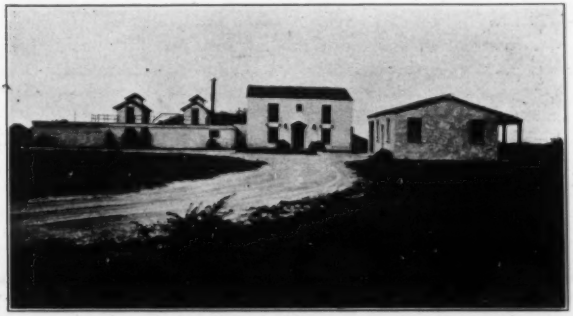


FIG. 1.—General View, Salinas Sewage Treatment Plant. Foreground: Aerators, Laboratory and Blower House, and Pumping Station. Background: Final Clarifier Houses and Digester.

hours at average flow. The design and operation of the primary settler digester, and sludge drying beds have been described in detail elsewhere[1] so further description of these units will be omitted.

Aerators.—The settled sewage flows to two aeration tanks which are operated in parallel. Each tank is 24 ft. wide, 64 ft. long and 12 ft. deep. A baffle extends 56 ft. along the center of the tank around which the sewage flows. The combined capacity of the two tanks is 33,740 cu. ft. Air is introduced through two rows of filtros plates along each side of the center baffle at 5.6 lbs. per sq. in. pressure. The plates form the "roof" of air ducts cast in the floor. Each row, which contains 40 plates, is controlled by a single valve. Provision is made for freeing the ducts of water whenever that is necessary.

Sewage enters the tanks through 8-in. cast iron pipes located directly over the plates and about 7 ft. above them. The mixed liquor flows out of the tanks over weirs. Figure 2 shows a cross section of one of the aerators.

Clarifiers.—There are two final settlers, operated in parallel, each of which is approximately 24 ft. square in plan at the surface, with sides sloped to form a circular bottom 22 ft. in diameter. The side water depth is 12 ft. These tanks are equipped with Dorr center-drive sludge collection mechanisms. The mixed liquor, which enters through three 6-in. horizontal pipes located along one side of each tank 8 in. below the surface, is directed downward by vertical baffles that extend 8 ft. 6 in. below the surface. The final effluent is drawn off over three weirs along the opposite side of the tanks. The total overflow weir length is 135 ft. 4 in. Each

TABLE I

AVERAGE OF 11 ANALYSES OF DAILY COMPOSITE SAMPLES COLLECTED THROUGHOUT THE YEAR 1930–31. ANALYSES MADE BY THE CALIFORNIA STATE DEPARTMENT OF HEALTH

Oxygen Consumed	218 p. p. m.
5 Day B. O. D.	489
Organic Nitrogen	23
Ammonia Nitrogen	42
Nitrate Nitrogen	0.5
Residue on Evaporation	1364
Loss on Ignition of Residue	651
Suspended Matter	361
Volatile Suspended Matter	304
Ether Soluble Matter	202
Insoluble Soaps	138
Total Fats and Greases	340
Settleable Solids	26 cc./liter
pH	7.3
Alkalinity	332 p. p. m.
Chlorides	220
Sulphates	111
Magnesium	28
Calcium	62

tank has a capacity of 6075 cu. ft. and a surface area, between the inlet baffle and the nearest overflow weir, of 422 sq. ft.

Sludge Handling Facilities.—As originally constructed, sludge was drawn by gravity from the final clarifiers to a small sump, from which it was pumped to the settled-sewage conduit, where it was mixed with the sewage before either entered the aerators. Variable-speed centrifugal pumps were used for this purpose; their maximum speed was 720 r. p. m. The maximum possible rate of sludge withdrawal with these facilities was 168 gal. per min., 22.5% of the peak hourly flow.

In February, 1931, it was thought that the introduction of sludge reaeration and an increased maximum rate of sludge withdrawal from the

final clarifiers might prove advantageous. Some slight changes in piping made it possible for the return sludge pumps to take their suction directly from the final clarifiers, thereby increasing the maximum possible rate of withdrawal to 336 gals. per minute. At the same time the settled-sewage inlet pipes to the aeration tanks were extended so that the sewage entered the aerators at a point three-eighths of the way down one side while the return sludge entered, as before, at the inlet end, thus making about 19 per cent of the aeration tank volume theoretically available for sludge reaeration. It is believed that the sewage backs up into the reaeration compartments considerably on peak flows, thereby materially reducing the volume of the aerators actually used for sludge reaeration. At the same

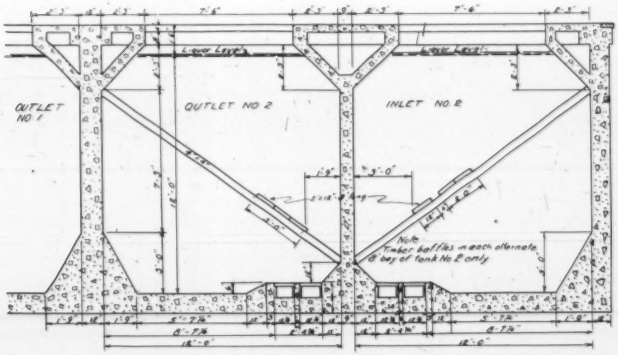


FIG. 2.—Location of Timber Baffles in Aeration Tanks for Dispersing Central Core in Spiral-Flow Tanks.

time provision was made for combining the excess activated sludge with the crude sewage for concentration in the primary settler before it was pumped to the digester.

The activated sludge is discharged to the reaeration compartments or to the crude sewage over weirs, so that definite knowledge of the rates of returning and wasting sludge can always be obtained. Orifice meters were provided for measuring the total air used and total sewage flow, but no provision was made for measuring the division of the air between the aeration tanks or the portion of the total sewage flow being aerated or its division between the two aeration units. More recently a Sparling meter was installed on the inlet of one of the aerators for the purpose of making the experiments hereinafter described.

Laboratory Control

The crude and settled sewages and the final effluent have been sampled hourly from 8 A.M. to 9 P.M. Suspended solids and ammonia nitrogen in the raw sewage, suspended solids in the settled sewage and suspended solids, ammonia, nitrite and nitrate nitrogen in the final effluent are determined daily on the composite samples. Total grease, pH and other tests are made less frequently. Samples of final effluent taken just *before* it passes over the final clarifier weirs are taken daily at 8:30 A.M., 1:30 P.M. and 7:30 P.M. for dissolved oxygen determinations and at 4 P.M. for relative stability determinations.

Samples for determining total, dissolved and suspended solids in the mixed liquor as it leaves the aerators are collected daily at 9 A.M., as is also a sample of the return sludge for determining solids and ash content. These tests are frequently repeated at other hours of the day. During certain runs dissolved oxygen and ammonia nitrogen tests have been made at various points throughout the aeration tanks. The percentage of sludge by volume in the mixed liquor is determined hourly or less frequently by allowing samples to stand for one hour in liter graduates. The time that the sludge will stay down in these graduates is also noted.

As an index of sludge bulking the sludge "density" was computed daily from the results of the 9 A.M. tests on the mixed liquor. The sludge "density," as the term is used in this paper, is the quotient of the suspended solids in the mixed liquor, expressed in parts per million by weight, divided by the per cent sludge by volume in the mixed liquor as determined after standing one hour in a liter graduate.

It will be noted that with the exceptions of the organic nitrogen and biochemical oxygen demand determinations a fairly complete knowledge of results obtained is available. The organic nitrogen determinations would be desirable to complete the picture of nitrification but aside from that would be of very little value. The biochemical oxygen demand test would probably be of greater value than any other single determination in calculating the work performed by the aeration process and its efficiency. Unfortunately the well water at the plant had such a high oxygen demand of its own that it was entirely unsuitable for a dilution water and as no other water was available without going to considerable expense and trouble the test has not been made a part of the laboratory routine.

Plant Operation

The plant was first put in operation May 27, 1930. Considerable trouble was encountered in building up a good activated sludge. After several attempts it was found to be impossible to build up a good sludge with a continuous flow through the aeration tanks so it was necessary to operate

on a fill-and-draw schedule until sufficient well aerated sludge was accumulated.

Operation without Sludge Reaeration.—After a good activated sludge was developed it was found to be possible to aerate about 400,000 gal. per day and to produce a very excellent effluent, as evidenced by the results in Table II, but whenever an attempt was made to treat more sewage the dissolved oxygen dropped and the sludge bulked. The bulking resulted in a very slimy, slow settling, floc that would not compact to a dense return sludge. As a result the sludge levels in the final clarifiers built up to the point where the floc passed out with the effluent. Greatly reducing or eliminating the flow to the aeration tanks for three to six days eliminated bulking temporarily.

During this period 950 cu. ft. of air per min., the maximum capacity of the blowers, was supplied continuously. Based upon the rate of returning sludge then in use and on an estimated sewage flow of 400,000 gal. per day about 3.4 cu. ft. of air per gal. of sewage and a 9.5-hour aeration period were used.

TABLE II

AVERAGE OF ANALYSES OF COMPOSITE SAMPLES COLLECTED ON DECEMBER 18 AND 19, 1930, AND JANUARY 26, 27, 28 AND 29, 1931. ANALYSES MADE BY CALIFORNIA STATE DEPARTMENT OF HEALTH

	Raw Sewage, P. p. m.	Settled Sewage, P. p. m.	Final Effluent, P. p. m.	% Removal by Prim. Treat.	% Removal by Comp. Treat.
Total Solids	1409	1145	885	18.7	37.9
Total Volatile Solids	658	527	289	20.0	56.1
Suspended Solids	440	185	25	58.0	93.7
Volatile Susp. Solids	384	157	...	59.2	..
Oxygen Consumed	223	173	48	22.4	97.8
5-Day B. O. D.	513	370	7.7	27.9	98.5
Organic Nitrogen	26.8	18.8	1.9	30.0	92.9
Ammonia Nitrogen	32.0	31.3	6.0	2.3	81.2
Nitrite Nitrogen	..	..	0.6	..	..
Nitrate Nitrogen	1.0	1.0	14.3	..	..
Dissolved Oxygen	..	..	0.7–2.0	..	..

A study of these results lead to the belief that considerably more air was required to keep the sludge in good condition than was needed to produce a fairly good effluent. It was thought that by sacrificing part of the aeration period of the mixed liquor, in order to reaerate the sludge, that bulking could be controlled to a considerable extent. It was also hoped that if the maximum rate of withdrawing sludge from the final clarifiers was increased it would be possible to prevent the sludge from building up in them to such an extent that it was carried over with the effluent even though it was somewhat bulked. These conclusions were the basis for the changes in sludge handling facilities that were made in February, 1931.

Operation with Sludge Reaeration.—Table III summarizes the results obtained when treating the entire sewage flow after the changes were made. During most of the time not accounted for in the table fifty to seventy-five per cent of the sewage was aerated and a stable well-nitrified effluent was produced. Table IV gives some of the daily average results obtained during Run 1, which are typical of those obtained in most of the other runs.

The changes in sludge density during the other runs were similar but more rapid. Table IV shows that, after the start of the run, the sludge density decreased more or less steadily until the sludge became so light that it would not compact in the final clarifiers. As the sludge density decreased the rate of returning sludge had to be increased to prevent the sludge from building up in the final clarifiers to such depths that it would be carried over with the effluent. Toward the end of the run the sludge bulked so badly that, even with more than sixty per cent

TABLE III

OPERATION WITH SLUDGE REAERATION

Run	Dates of, 1931 Start	End	Length of Run, Days	Sewage Aerated, G. P. D.	Sludge Return, % of Sewage	Air Used, C.F./Gal. Sewage	Hours: Sewage Aeration	Hours: Sludge Reaeration	Mixed Liquor, Outlet Aerators, 9 A.M.: Dis. Solids, P. p. m.	Mixed Liquor, Outlet Aerators, 9 A.M.: Susp. Solids, P. p. m.	Mixed Liquor, Outlet Aerators, 9 A.M.: Sludge Density	Return Sludge, 9 A.M.: Dry Solids, %	Return Sludge, 9 A.M.: Ash, %	Crude Sewage: Susp. Solids, P. p. m.	Crude Sewage: Ammonia Nitrogen, P. p. m.	Settled Sewage, Susp. Solids, P. p. m.	Final Effluent: Susp. Solids, P. p. m.	Final Effluent: Nitrogen as Ammonia, P. p. m.	Final Effluent: Nitrogen as Nitrite, P. p. m.	Final Effluent: Nitrogen as Nitrate, P. p. m.	Final Effluent: Relative Stability 4 P.M., %	Final Effluent: Dissolved Oxygen, P. p. m.
1	3–2	3–25	24	509	47.7	2.65	6.7	5.5	781	2800	83	0.91	25.1	633	29.0	251	28	8.0	2.8	7.7	62	0.8
2	4–1	5–3	33	625	34.8	2.21	5.9	5.8	850	2159	120	0.77	22.4	515	34.1	211	22	28.0	0.8	1.7	14	0.4
3	5–24	6–3	11	578	63.0	2.38	5.2	3.1	776	2215	43	0.55	23.8	601	44.0	178	5	10.7	1.7	10.0	99	0.7
4	6–9	6–17	9	590	55.1	2.37	5.5	3.6	811	2164	73	0.64	21.7	519	38.0	163	17	12.2	2.1	5.4	96	0.8
5	6–29	7–10	12	670	47.3	2.03	4.8	3.4	992	2224	89	0.72	22.5	454	37.1	175	13	12.1	1.4	3.2	81	1.2
6	8–1	8–4	4	639	60.1	2.18	5.0	3.1	908	2104	64	0.50	24.9	497	41.3	224	11	17.5	0.9	3.8	92	0.8
7	8–10	8–14	5	721	52.4	1.88	4.6	3.0	1074	2345	57	0.60	24.8	500	38.4	268	17	21.3	1.1	1.9	34	0.6
8	8–19	8–24	6	685	30.1	1.87	5.6	6.1	1032	2095	69	0.66	24.7	587	43.6	281	15	21.0	2.4	3.2	23	0.7

return, the sludge depths in the clarifiers were 7 to 9 ft. during high daytime flows. It is probable that the rates of returning sludge used during the latter parts of the run were so high that they reduced the period of sludge reaeration to such an extent that it was of very little benefit.

TABLE IV

RUN 1, DAILY RESULTS

Date	Hours: Sewage Aeration	Hours: Sludge Reaeration	Total Air, C.F./Gal. Sewage	Sludge Return Per Cent	Mixed Liquor Outlet Aeration, 9 A.M.: Susp. Solids, P. p. m.	Sludge by Vol. 1 Hr. Standing	Sludge Density	Return Sludge 9 A.M.: Solids, %	Return Sludge 9 A.M.: Ash, %	Depth of Sludge in Clarifier, Ft.	Final Effluent: Susp. Solids, P. p. m.	Final Effluent: Av. Relative Stability, 4 P.M., %
3-2	6.5	4.6	2.68	48.1	2976	19	157	0.9	25.8	3+	41	99+
3	5.9	3.7	2.59	59.3	3167	20	154	1.0	26.1	4	30	99+
4	6.4	4.0	2.79	57.4	3572	22	162	1.0	25.2	3	26	60
5	6.9	4.5	2.95	54.4	3404	21	158	1.2	25.4	3	20	97
6	7.6	7.1	2.78	32.8	3202	21	152	1.1	24.4	3	16	99
7	7.2	5.7	2.81	41.1	3202	21	149	1.1	22.8	2+	17	97
8	8.9	6.7	3.57	44.1	3178	21	151	1.0	22.4	2	21	99+
9	6.9	5.9	2.65	37.0	3140	22	140	1.2	22.1	3	18	98
10	7.9	9.9	2.71	22.5	3195	27	118	1.5	20.7	3	43	35
11	7.3	7.7	2.63	28.4	2616	19	134	1.4	21.4	4+	22	48
12	7.9	11.0	2.69	20.0	2986	25	116	1.6	18.5	4	18	30
13	8.0	11.6	2.60	19.0	2935	26	112	1.0	20.9	5	30	11
14	6.2	4.5	2.52	44.7	3926	53	74	1.3	21.6	8	25	16
15	8.3	8.6	3.00	28.8	3877	73	53	1.0	27.2	5	10	55
16	5.8	4.0	2.43	50.9	2525	32	78	1.2	21.1	7+	7	20
17	6.0	3.8	2.65	57.9	2962	53	55	0.7	23.8	5	6	64
18	6.3	3.9	2.82	60.6	2835	61	47	0.6	28.1	8	...	59
19	6.2	3.7	2.78	64.7	2791	62	45	0.6	24.7	10	11	77
20	6.1	4.2	2.50	51.3	2215	59	37	0.5	26.1	9+	23	64
21	5.9	3.6	2.55	61.6	1812	32	56	0.4	23.4	9	23	64
22	6.0	3.5	2.71	67.5	1630	29	55	0.4	34.7	8	26	99
23	5.7	3.6	2.45	57.4	1670	28	59	0.4	29.5	8+	56	37
24	5.4	3.0	2.53	69.3	1516	30	50	0.4	24.9	8+	59	35
25	5.1	2.9	2.33	66.1	1865	36	51	0.4	31.6	9	103	24

As shown in Table III by the relative stability and nitrate content of the effluents, poorer results were obtained during Run 2 than during any of the other runs. But, even in the middle of this run, April 13 to 18, inclusive, analysis of composite samples made by the California State Department of Health showed over-all reductions of 5-day B. O. D. and organic nitrogen of 93.8 and 78.3 per cent, respectively. During this period the corresponding reductions by primary treatment alone were 28.2 and 33.4 per cent, respectively.

These data show that even after the changes in sludge handling facilities were made the entire flow could not be treated without periodic bulking of

the sludge and that as the volume and strength of the sewage increased with the advent of summer the time between "bulkings" decreased. However, results indicated that a larger volume of sewage could be treated with the same total amount of air and less rapid bulking of the sludge than was the case before the changes were made, although not quite as good an effluent was produced. A study of these results seemed to indicate the following:

1. The sludge density didn't simply drop to a certain minimum at which point it would remain constant, but apparently it would continue to decrease until it became so low that there was very little separation of the floc from the liquor. Therefore the increased sludge return capacity was of little or no benefit. Extremely high rates of returning sludge were probably harmful because they decreased the sludge reaeration period and, to a lesser extent, the aeration period of the mixed liquor.

2. Sludge reaeration was of some benefit in retarding bulking. This indicated that if the reaeration period could be increased without further decreasing the aeration period of the mixed liquor, considerably more benefit would be realized. This indicated the necessity of obtaining a return sludge of higher solid content.

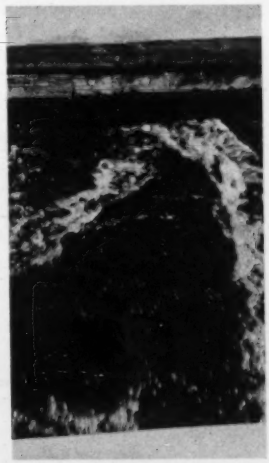
3. Either more air, or more efficient aeration, or both were required. Because of limited blower capacity, air had been supplied at a uniform rate, which meant that although the daily averages ranged from 1.9 to 2.6 cu. ft. of air per gal. of sewage the actual air supplied ranged from 1.3 cu. ft. per gal. on peak flows to 4.7 cu. ft. per gal. on low night flows. It was thought that additional air on peak flows was particularly necessary.

Experiments were therefore undertaken to determine (*a*) means of increasing the efficiency of the aerators, (*b*) means of increasing the solid content of the return sludge and (*c*) how much air was required and how it should be varied with the sewage flow.

Experimental Operation

Aerator Efficiency.—Due, possibly, to the fact that the flowing-through channels of the Salinas aerators had the same width as depth, aeration appeared very violent and it was thought possible that the air did not remain in contact with the liquor long enough to permit the maximum absorption of its contained oxygen. Tests indicated that there was also considerable short circuiting; the actual aeration period was from 50 to 80 per cent of the theoretical period. Current-meter velocity determinations showed the presence of a central core in which there was very little movement. The diameter of this core increased as the amount of air and hence the surface velocity increased. It is believed that much of the incoming sewage traveled in a spiral course around this core and hence the full benefit of the tank was not developed. To correct these difficulties

some timber baffles, shown in Figure 2 were placed in each alternate eight-foot bay of aerator No. 2. Figures 3 and 4 show the affect of these baffles on the appearance of the aerators. Tests showed that due to reducing the short circuiting, and possibly to a lengthening of the contact period of the air bubbles with the mixed liquor, it was possible to treat about 15% more sewage in the baffled tank than in the unbaffled one and to obtain an equally good effluent when using the same amount of air in each tank. Due to piping arrangements it was not possible to keep the sludge from



Baffled: 2.75 Cu. Ft. Air per Sq. Ft. Plate Area

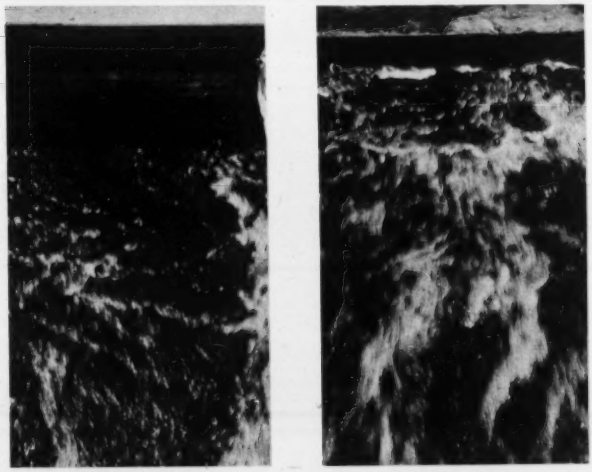
Unbaffled: 3.00 Cu. Ft. Air per Sq. Ft. Plate Area

FIG. 3.—Looking Toward Filtros Plates.

each tank separate during those tests. It is believed that by making the baffles continuous throughout both aerators their efficiency can be increased fully twenty-five per cent. These experiments have been described in more detail elsewhere.[2] Table V shows the results of the current-meter velocity determinations.

Solids Content of Return Sludge.—The solids content of the return sludge may be increased by increasing the rate of flow of mixed liquor, increasing the density of the sludge, increasing the amount of suspended matter in the mixed liquor, increasing the depth of sludge in the settlers,

and decreasing the rate of withdrawing sludge. Obviously the last three means are the only ones amenable to ready control. Since increasing the solid content of the mixed liquor would increase the air requirements, that was undesirable. At Salinas the depth of the sludge in the clarifiers is now determined hourly and an attempt is made to keep the rate of withdrawal as low as possible without accumulating more than a one-foot depth of sludge at the sides of the clarifiers. Experience at Salinas seems to



Baffled: 2.75 Cu. Ft. Air per Sq. Ft. Plate Area

Unbaffled: 3.00 Cu. Ft. Air per Sq. Ft. Plate Area

FIG. 4.—Looking Away from Filtros Plates.

indicate that bulking occurs more rapidly when greater depths of sludge are carried in the clarifiers and this agrees with the experience of others; Harris, Cockburn and Anderson[3] state that "undue detention in the settlement tanks lowers the density of the sludge and increases its volume."

Through the coöperation of the Dorr Company, Inc., some experiments have been started to determine the effect of the speed of the sludge collecting mechanisms on the solid content of the sludge. Preliminary results indicate that changing the speed from $^1/_7$ to $^1/_{20}$ r. p. m. increased the solids in the sludge withdrawal from 1.26 to 1.48 per cent, but additional experiments along this line are desirable.

TABLE V

EFFECT OF BAFFLING ON "CORE" IN SPIRAL-FLOW TANKS

Location	Approx. Air Cu. Ft. per Sq. Ft. Plate Area	Transverse Velocity Feet per Second			Vertical Diam. of Core Having Velocity Less than		
		Average Surface	Minimum	11 Ft. Depth	0.3 Ft. per Sec.	0.6 Ft. per Sec.	1.0 Ft. per Sec.
Inlet Tank No. 1 Unbaffled	3.00	1.07	3.18	0.33	1.76	0.00	6.18	7.76
Outlet Tank No. 1 Unbaffled	2.00	0.92	2.02	0.17	1.57	3.04	5.44	7.58
Inlet Tank No. 2 Baffled Bays	2.75	0.99	2.17	0.24	1.50	1.86	4.97	7.51
Inlet Tank No. 2 Unbaffled Bays	2.75	..	3.49	0.28	..	..	..	..
Inlet Tank No. 2 Baffled Bays	7.25	1.32	3.13	0.53	1.96	0.00	1.80	7.27
Inlet Tank No. 2 Unbaffled Bays	7.25	1.32	3.63	0.28	1.81	0.39	5.16	6.44
Outlet Tank No. 2 Baffled Bays	2.25	1.18	2.43	0.30	1.26	0.00	3.84	6.32
Outlet Tank No. 2 Unbaffled Bays	2.25	0.94	2.98	0.26	1.29	1.74	6.31	8.39
Outlet Tank No. 2 Baffled Bays	4.88	1.31	3.10	0.50	1.57	0.00	3.81	6.32
Outlet Tank No. 2 Unbaffled Bays	4.88	1.33	3.96	0.49	1.76	0.00	3.32	8.01

TABLE VI

EXPERIMENTAL RUNS USING HALF OF PLANT

Run	Dates of, Start	Dates of, End	Hours, Length of Run, Days	Hours, Sewage Aerated, G. P. D.	Hours, Sludge Return, % of Sewage	Hours, Air Used, C.F./Gal. Sewage	Mixed Liquor Outlet Aerators 9 A.M., Sewage Aeration	Mixed Liquor Outlet Aerators 9 A.M., Sludge Reaeration	Mixed Liquor Outlet Aerators 9 A.M., Dis. Solids, P. p. m.	Mixed Liquor Outlet Aerators 9 A.M., Susp. Solids, P. p. m.	Mixed Liquor Outlet Aerators 9 A.M., Sludge Density	Return Sludge 9 A.M., Dry Solids, %	Return Sludge 9 A.M., Ash, %	Crude Sewage, Susp. Solids, P. p. m.	Crude Sewage, Ammonia Nitrogen, P. p. m.	Crude Sewage, Settled Sewage Susp. Solids, P. p. m.	Final Effluent, Susp. Solids, P. p. m.	Final Effluent, Nitrogen as, Ammonia, P. p. m.	Final Effluent, Nitrogen as, Nitrite, P. p. m.	Final Effluent, Nitrogen as, Nitrate, P. p. m.	Final Effluent, Relative Stability 4 P.M., %	Final Effluent, Dissolved Oxygen, P. p. m.
A	11-3	11-13	11	328	14.1	2.28	6.8	14.4	826	1164	140	0.5	20.6	491	52.3	227	25	32.5	2.21	6.2	46	0.8
B	11-28	12-8	11	332	7.9	2.68	6.9	22.1	717	1213	173	1.2	30.4	626	51.4	193	14	30.0	2.13	9.6	99+	1.7
C	12-9	12-16	8	316	9.8	4.33	7.1	20.1	642	1095	55	0.9	24.4	509	52.5	170	45	31.8	1.17	8.8	96+	0.8
D	12-23	1-10	19	323	10.0	4.20	6.9	18.4	1070	1400	141	1.3	29.1	384	44.0	179	22	12.7	0.94	15.0	99+	3.2
E	1-15	1-29	15	332	8.0	3.35	6.9	22.3	1336	1403	163	1.1	26.3	379	45.5	152	24	8.4	2.75	15.6	99+	4.4

Air Requirements.—To determine the air requirements, only one aerator, the baffled one, and one clarifier were used. Slightly less than half the peak summer flow was treated in these units. The hourly variations in the amount of sewage treated were made, as nearly as possible, similar to those in the summer flow. Five separate runs were made, in which differing amounts of air were used. Table VI summarizes the five runs.

A comparison with Table III shows that although the sewage varied somewhat in strength it was always at least as strong as the average summer sewage.

Table VII shows the average hourly variations in amounts of sewage treated and Figure 5 shows the hourly variations in air used.

At the start of Runs A, B and E the sludge was in an over-aerated condition. The sludge was slightly bulked at the start of Run D although it had been aerated for a few days previous to starting. Run C followed immediately after Run B; the sludge was just starting to bulk seriously at the first of this run.

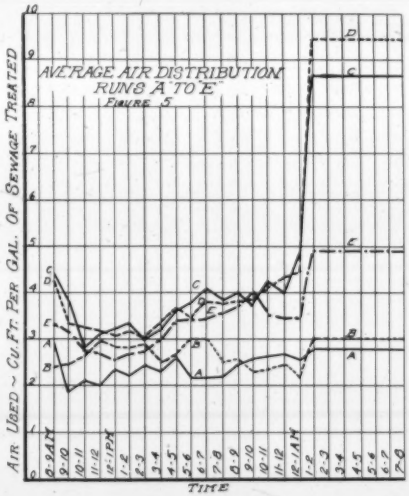


FIG. 5.—Hourly Distribution of Air, Nov. 3, 1931, to Jan. 29, 1932.

In Runs A and B the air used per gallon of sewage was held as nearly constant throughout the day as was possible. During both of these runs the dissolved oxygen in the clarifier was very much lower at 8:30 A.M. and 7:30 P.M. than at 1:30 P.M. and the sludge bulked badly. This indicated that more air was required and that more air per gallon of sewage should be used during the night flow than during the peak flow. Therefore most of the increases in air used that were made in Runs C, D and E were during the low night flows of sewage. In these runs the dissolved oxygen results at 8:30 A. M. and 1:30 P. M. were nearly equal but there was still an appreciable drop in the 7:30 P.M. results, in spite of the fact that the total air used was 950 cu. ft. per min. throughout the twenty-four hours in Runs

TABLE VII

AVERAGE AMOUNT OF SEWAGE TREATED AT VARIOUS HOURS OF DAY

Time	Average Gallons Sewage Aerated During Run A	Run B	Run C	Run D	Run E
8–9 A.M.	9,400	12,100	13,000	13,200	12,000
9–10	16,800	17,400	15,700	17,100	17,800
10–11	19,300	21,400	19,300	17,900	20,000
11–12	21,600	19,200	19,300	18,200	19,600
12–1 P.M.	20,250	20,400	18,000	18,500	20,800
1–2	19,600	19,900	17,900	18,600	19,800
2–3	16,900	16,700	17,100	18,900	19,900
3–4	17,750	18,600	18,700	18,200	17,600
4–5	14,600	17,200	16,100	15,600	16,800
5–6	15,800	15,900	15,100	16,500	15,400
6–7	16,550	14,900	14,300	15,800	16,000
7–8	15,100	14,800	15,700	15,100	15,500
8–9	14,500	15,200	14,200	15,100	14,900
9–10	12,900	15,100	15,200	15,000	14,200
10–11	11,800	14,800	13,700	12,900	13,400
11–12	10,700	14,100	14,300	12,900	13,500
12–1 A.M.	11,200	13,600	12,500	12,700	13,200
1–8	64,700	52,000	46,800	51,200	53,400

C and D and from 9 A.M. to 10 P.M. in Run E. This drop in dissolved oxygen must have been due to an increased oxygen demand of the sludge, as will be shown later, but inasmuch as a comparatively high oxygen content was maintained even at 7:30 P.M. and no bulking occurred, it was not believed that additional air was required.

Table VIII shows the average dissolved oxygen in the effluent at each sampling time in Runs A to E inclusive and also in Runs 1 and 2, which have been included for comparison.

The results obtained in these runs showed: (1) that 2.7 cu. ft. of air per gal. of sewage was not enough to prevent sludge bulking but that a stable,

TABLE VIII

DISSOLVED OXYGEN CONTENT OF FINAL EFFLUENT

Run	8:30 A.M. P. p. m.	1:30 P.M. P. p. m.	7.30 P.M. P. p. m.
1	0.91	0.89	0.74
2	0.38	0.35	0.40
A	0.32	0.74	0.43
B	1.12	2.77	1.15
C	0.83	1.11	0.48
D	3.52	3.72	2.28
E	5.00	4.86	3.43
	Omitting First 6 Days		
D	3.99	4.21	2.77
E	4.17	3.96	2.57

well-nitrified effluent could be produced for at least eleven days (the duration of Run B) when using that amount of air; (2) that if the sludge was in good condition initially, no serious bulking would be encountered when using 3.35 cu. ft. of air per gal. of sewage; (3) that once the sludge started to bulk, even 4.3 cu. ft. of air per gal. of sewage was not enough to bring it back, but that once its improvement had been started this was sufficient air to bring it to first-class condition.

It is interesting to note that the practice of reaerating the sludge had little or no effect on the air requirements, but that reaeration together with the baffling of the aerators made it possible to treat about sixty per cent more sewage in the same tank capacity, when using the same amount of air per gallon of sewage as was used without sludge reaeration.

These tests also showed: (1) that the hourly variations in amount of air used should be much less than those in the amount of sewage treated; (2) that when larger amounts of sludge were used, as in Runs 1 and 2, the air should be applied at a uniform rate, but that when smaller amounts were used, as in Run E, some reduction in air used could be made during the night; (3) that the condition of the sludge had a marked effect on the amount of air required. For example, higher dissolved oxygen results were obtained during Run E than during Run D although less air was used and slightly more sewage was treated; this was due chiefly to the poor condition of the sludge at the start of Run D and its over-aerated condition at the start of Run E, for if the first six days of each of these runs are omitted the average dissolved oxygen results were practically the same.

In connection with the hourly variations in the amount of air used Grant, Hurwitz and Mohlman[4] state that "mixtures of sewage plus sludge absorb oxygen in proportion to the weight of sludge, but that with increasing amounts of sludge most of the oxygen demanding material of the sewage is coagulated or adsorbed by the sludge, so that very little oxygen is required for the unadsorbed material in true solution. Adjustment of the rate of air supply should be governed by the amount of sludge in the aeration tanks. With large amounts a fairly uniform rate (expressed in cu. ft. per min.) is desirable."

Another point worthy of consideration is the proper distribution of the air between the various parts of the aeration and reaeration tanks. Harris, Cockburn and Anderson[3] state that their experiments "proved that the dissolved oxygen adsorbed by the sludge is a constantly decreasing amount from its contact with the inflowing sewage to its discharge from the reactivation channels (aerators). The starting point of the process of reactivation (biological oxidation) may be accepted as the point nearest the inflow of the aeration tank at which dissolved oxygen first appears. The degree of reactivation (biological oxidation) that takes place in the aeration tank is dependent upon the balance maintained between the supply of and

the demand on the dissolved oxygen and the period of detention as timed from the determined starting point." This would indicate that a long period of contact of the sludge with some dissolved oxygen would be of greater benefit than a short period of contact with more dissolved oxygen. With this in mind dissolved oxygen determinations have been made, at various times, at the middle of the sludge reaeration compartments and near the inlet, middle and outlet of the aeration compartments at various rates of sewage flow and air consumption. The distribution of the air to the various parts of the tanks was so adjusted that (1) there was an appreciable amount of dissolved oxygen in the reaeration compartments; (2) there was at least a small amount at the inlet of the aeration compartments; and (3) the dissolved oxygen gradually increased toward the outlet of the aeration compartments. It was found that when these conditions were all satisfied that considerably more sewage could be treated without encountering bulking than could be treated when distributing the air uniformly throughout the aerators, although the dissolved oxygen in the effluent was slightly lower. It was found necessary to use from 55 to 70 per cent of the air on the inlet sides of the aerators to satisfy these conditions; the percentage increases some with increased sewage flows, decreased air supplies or bulked sludge and vice versa.

Microscopical Examinations

Throughout 1931 frequent microscopical examinations of the sludge at the outlets of the aeration tanks were made. The more important results of these examinations may be summarized as follows:

1. After protracted periods of sludge aeration, without the addition of sewage, there were comparatively few organisms present and those that were present appeared very sluggish.
2. Protozoa were always present in greater or less numbers. Ciliates far outnumbered flagellates in all samples. Peretricha were present in nearly all samples, usually in goodly numbers. Hypotricha were frequently observed while holotricha and heterotricha were seen only occasionally. The heterotricha and holotricha were never found in poor sludge but were usually present, at least in small numbers, in good sludge.
3. *Sphaerotilus* was always present in a bulked sludge; usually it was the predominating organism observed in a badly bulked sludge. It was never found in a good sludge.
4. Rotifers were present in about half the samples examined. Their presence or absence could not be correlated with either the density of the sludge or the quality of the effluent.

Of these observations the invariable presence of *sphaerotilus* in a bulked or poor sludge seemed to be the most important under Salinas conditions.

When the sludge was infested with these organisms it was usually very light, slimy and sticky; occasionally it contained pellets surrounded by slime that settled quite rapidly. On a few occasions these pellets were so numerous that the sludge had a granular appearance. At such times its density was high but usually the density was below 100 when *sphaerotilus* was present. The presence of this organism was usually accompanied by reduced nitrification and lower dissolved oxygen. Under the microscope the floc appeared to consist almost entirely of entwined filaments and the pellets appeared to be more solidly wound clumps of the organisms.

It is interesting to note that *sphaerotilus* growths were present throughout Run 2. Their presence may explain the poorer effluent obtained during that run. At the start they were almost entirely present in the "pellet form" and the sludge was very dense and granular; they decreased considerably and then increased again in the "expanded form" with accompanying bulking of the sludge.

The literature[5,6,7] contains several references to the correlation between sludge bulking, *sphaerotilus* and the presence of sugars in the sewage. Therefore, tests for sugar in filtered samples of the raw and settled sewage, using a modified form of Benedict's qualitative analysis of urine, were made for several months. Although *sphaerotilus* appeared and disappeared several times during that period the presence of sugar in the sewage was never confirmed.

Discussion

During the varied though brief operation of the Salinas plant, several observations have been made and conclusions drawn that, it is believed, may be of quite general application to the activated-sludge process and of considerable aid to the operators of small difficult plants.

Mode of Action of Activated Sludge.—One commonly accepted theory of the mode of action of activated sludge is that the surfaces of the floc adsorb the finely divided suspended matter, the colloids and also some of the dissolved matter in the sewage, and that much of this adsorbed matter is then liquefied and/or gasified by biological oxidation; without this oxidation the floc surfaces become so glutted that they can adsorb no additional material. It would appear logical that, if this theory is correct, the rates of adsorption and oxidation should be balanced one against the other. In the opinion of the writer the disturbance of this balance is the fundamental cause of most of the troubles encountered in the activated-sludge process.

Changes Undergone by Sludge During Prolonged Aeration.—In a normally operating aeration tank there are so many variables that it is difficult to demonstrate the application of the above theory, but the changes undergone by the sludge during prolonged aeration without the

addition of any sewage may be of interest in this connection. Some of these changes are shown in Tables IX and X.

At the end of Run 6, 3 P.M. Aug. 4, 1931, the sludge was badly bulked and presumably the floc surfaces were saturated with adsorbed material. At that time all sewage was shut out of the aerators and the sludge in the final clarifiers was pumped back into the aerators. From then until 9 A.M.

TABLE IX

AERATION WITHOUT ADDITION OF SEWAGE

Date	Mixed Liquor Analyses Outlet of Aerators at 9 A.M. Total Solids, P. p. m.	Susp. Solids, P. p. m.	Diss. Solids, P. p. m.	Sludge Density	Hours that 9 A.M. Samples of Sludge Stayed Down in Liter Graduates
Aug. 4	3342	2539	803	43	16 plus
5	3496	2516	980	69	2¼
6	3204	2099	1105	73	3¼
7	3159	1979	1180	77	4
8	3148	1892	1256	79	7½
9	3122	1817	1305	82	11
10	3102	1738	1364	85	11½

Aug. 10, the contents of the aerators were aerated at a uniform rate of 950 cu. ft. of air per min., without the addition or removal of any liquor or sewage. Table IX shows a continuous decrease in suspended solids and an accompanying increase in dissolved solids throughout the period, thus showing the progress of liquefaction. The total solids increased the first day, due to the removal of all of the sludge from the final settlers, but

TABLE X

DECREASE IN pH ON PROLONGED AERATION

Date	Time	pH of Mixed Liquor	Remarks
Dec. 29, 1930	8:30 A.M.	7.0	All sewage shut out of aerators at 9:30 A.M.
Dec. 30, 1930	4:00 P.M.	6.8	
Jan. 1, 1931	11:00 A.M.	6.4	Sewage turned into aerators at 11:30 A.M.

decreased thereafter; this reduction must have been due to gasification. The time that the sludge stayed down in the graduates is primarily dependent upon the amount of gas liberated by the sludge. The data in Table IX show that there was little or no gasification at the end of Run 6, but as soon as the flow was by-passed gasification became quite active; after the third or fourth day of continued aeration gasification fell off considerably. It is significant that the reduction in both total and suspended solids was greatest during the period of active gasification.

It has also been noted that the pH of the aerator contents has always dropped during periods of prolonged aeration, although the drop was much greater on some occasions than on others. Table X shows the progress of this action during one period.

Another change observed during prolonged aeration is an increase in the ash content of the sludge. During normal operation it has ranged from 35 to 17 per cent, usually averaging between 25 and 22 per cent; after prolonged aeration, without the addition of any sewage, it has ranged from 35 to 40 per cent. This would indicate that the volatile content of the sludge might serve as a rough measure of the amount of unoxidized matter adsorbed by the floc surfaces.

These various changes in the sludge were noted, to a greater or less extent, during every period of prolonged aeration at Salinas. They led to the belief that determinations of pH, dissolved solids, ash content and rate of gasification as measured by the time the sludge stayed down might serve as valuable means of determining and controlling the balance between adsorption and oxidation within the sludge. The value and significance of each of these tests will now be considered separately.

pH Determinations.—pH determinations were made on the daily composite samples of sewage and final effluent throughout Runs B, C, D and E. The sewage pH ranged from 7.0 to 7.5 and, in general, the daily

TABLE XI

REDUCTION OF pH VALUE

Run	Average pH of Sewage	Final Effluent
B	7.26	7.25
C	7.24	7.23
D	7.46	7.35
E	7.42	7.38

variations in pH of the final effluent followed those in the sewage. The average results for each run are given in Table XI. It is interesting to note that the reduction in pH by aeration was very slight during Runs B and C and that the sludge bulked during those runs, while in Runs D and E, in which no serious bulking occurred, the pH reduction was appreciably greater. It was much greater in D, in which 4.2 cu. ft. of air per gal. of sewage was used, than in E, in which 3.35 cu. ft. of air per gal. was used. These observations are in line with those made during prolonged aeration, but it appears that the pH reduction during normal operation is too slight to be of any practical value as a measure of the oxidation-adsorption balance.

Dissolved Solids Determinations.—These determinations, as ordinarily made, include the colloids as well as the truly dissolved matter. If adsorption is progressing at a much faster rate than oxidation one would expect the dissolved solids in the mixed liquor, or in the final effluent, to be appreciably lower than those in the sewage, while if liquefaction (oxidation) were progressing faster than adsorption the reverse should be true. An

inspection of the data in Tables III and VI show that apparently this is true. During Runs D and E, the only runs during which serious bulking did not occur, the dissolved solids in the mixed liquor ranged from 1000 to 1500 p. p. m., for the most part, while in all other runs they ranged between 600 and 1000 p. p. m. (Runs 6, 7 and 8 were so short that the high dissolved solids on the first day had a marked effect on the averages for those runs). The dissolved solids in the sewage itself, as determined only occasionally, ranged between 1000 and 1200 p. p. m.

Table VI shows that the dissolved solids averaged 1070 p. p. m. during Run D and 1336 p. p. m. during Run E, or 334 p. p. m. higher during E than during D. One would expect the reverse to be true, judging from the amount of sewage treated, amount of air used and results obtained. This discrepancy is explained by the fact that as previously stated, the sludge at the start of Run E was overaerated while at the start of Run D it was slightly bulked. During the first six days of Run D the dissolved solids averaged 742 p. p. m. as compared with 1448 p. p. m. in Run E; during the remainder of the runs the dissolved solids were 1222 and 1260 p. p. m., respectively, or practically the same.

No correlation has been found between the daily fluctuations in dissolved solids and variations in quality of the effluent or the sludge density. Apparently the most that can be said for this test is that if the dissolved solids in the mixed liquor are maintained slightly higher than those in the sewage one can be sure that liquefaction (oxidation) is progressing at least rapidly enough to keep pace with adsorption.

Rate of Gasification.—Gasification was so slow throughout Runs 1 to 8 and A to C, inclusive, that, with the exception of a few scattering days, the sludge stayed down in the liter graduates for more than six hours. The few days during which gasification was more pronounced were either preceded or accompanied by increases in ammonia reduction, nitrification, and relative stability, but all increases in any or all of these were not necessarily accompanied or followed by sufficient increases in gasification to cause the sludge to rise in the graduates in less than six hours. There was no correlation between the daily variations in sludge density and the time that the sludge stayed down in the graduates. It is significant, however, that throughout Runs D and E, the only runs in which serious bulking did not occur, the hourly sludge samples rose in from 1 to $3^1/_2$ hours, while ammonia reduction, nitrification and relative stabilities were all high.

Ammonia determinations made at various points throughout the aerators indicate that there is always a rapid reduction in ammonia soon after the sewage comes in contact with the sludge, but unless gasification is sufficient to cause the sludge to rise in the graduates in less than six hours there is very little, if any, further reduction in ammonia as the sewage progresses through the aerators. These observations seem to

indicate that gasification is more important than liquefaction in the oxidation of adsorbed nitrogenous matter.

It has been noticed that when sewage is first turned into the aerators after prolonged aeration there is an enormous, immediate increase in gasification; the sludge comes up much more rapidly than it ever does during aeration without the addition of sewage. Table XII shows this phenomenon at the start of Run 8. When insufficient air is used, as was the case in Run 8, gasification soon subsides, but when sufficient air is used, as in Run E, there is only a slight and gradual subsidence in gasification. This has led to the belief that very rapid rising of the sludge may indicate over-aeration (excessive oxidation), but that this holds true only for normal operation; over-aeration may be obtained when no sewage enters the aerators without producing rapid gasification because at such times there is only a very limited amount of adsorbed material to be gasified.

TABLE XII

FLOTATION OF SLUDGE

Date	Time Sludge Collected	Hours That Sludge Stayed Down in Liter Graduates	Remarks
Aug. 19	8 A.M.	8 1/4	
	1 P.M.	8	Sewage turned into aerators at 1 P.M.
	5 P.M.	2	
	7 P.M.	1 1/4	
	11 P.M.	1 1/4	
Aug. 20	8 A.M.	1 3/4	
	11 A.M.	1 1/2	
	1 P.M.	1 1/4	
	3 P.M.	10 plus	Samples thrown out at 1 A.M.
	4 P.M.	9 plus	

Observations indicate that the time that the sludge stays down is not only dependent upon the condition of the sludge but also upon the size and shape of the vessel in which the samples stand, the temperature of the mixed liquor in the aerators and the temperature of the samples while standing. Because of the various factors in addition to the sludge condition that affect the time, and because of the rapid changes which it undergoes when the sludge is on the border line (see results at 1 and 3 P.M., Aug. 20, Table XII which are typical) the exact time is of little value as an indicator of sludge conditions. But, when reasonable care is taken to control the other variables, the fact that the sludge will rise in a few hours assures the production of a well-nitrified, stable effluent and if it rises very quickly (3/4 to 1 1/2 hours) the sludge is probably over-aerated.

Ash Content of Sludge.—If it is true that the volatile content of the sludge serves as a rough measure of the amount of unoxidized matter

adsorbed by the floc surfaces, one would expect the volatile content of the sludge to increase slightly during the peak flow of strong day-time sewage and to decrease during the low flow of weaker night sewage. Table XIII shows that this was the case throughout Runs B, C and E. During Run D the variation throughout the day was very slight, but in the opposite direction. Similar data on the other runs were not obtained.

TABLE XIII

Run	Average Volatile Content of Return Sludge at 9 A.M.	2 P.M.	7 P.M.
B	69.62%	.....	71.21%
C	74.61%	75.35%	75.67%
D	70.83%	70.73%	70.32%
E	70.87%	72.13%	73.55%

Therefore, it would appear that, theoretically at least, if biological oxidation of the adsorbed matter is progressing satisfactorily, the volatile content of the sludge at any given hour should be the same from day to day; an increase in the volatile content would indicate that oxidation was not keeping pace with adsorption while the reverse would indicate greater oxidation than adsorption. Actually there are bound to be slight variations from day to day due to fluctuations in the character and quantity of sewage treated, the amount of air used and possibly the amount of sludge carried. A careful inspection of the data in Table IV shows that 88% of the time a drop in the ash content (rise in volatile content) of the return sludge at 9 A.M. was either accompanied or followed by a drop in the sludge density while a rise in the ash content was accompanied or followed by either a rise in the sludge density or a marked retardation of the decrease in density. The same relationship was noted in the other runs, and Harris, Cockburn and Anderson[3] have made similar observations at the Shieldhall, England, plant.

Apparently the daily variations in ash content are of more significance than the actual ash content is. For example, during Run B the ash content was more than 27% until the last day, although the sludge bulked, while it averaged 26.3% in Run E and no bulking occurred.

Causes of Sludge Bulking.—At Salinas serious bulking has occurred only after extended periods in which gasification and dissolved solids in the mixed liquor, and dissolved oxygen in the effluent, were low, and during which the ash content of the sludge continually decreased. It has just been stated that the density of the sludge increased or decreased when its volatile content decreased or increased. However, the variations were not directly proportional to the variations in ash content. When the density of the sludge was either very high or quite low the tendency for the density to vary with the ash was less pronounced. This was particularly noticeable at low densities where the density apparently decreased re-

gardless of the ash content. These observations indicate that *the primary cause of sludge bulking is insufficient biological oxidation to keep pace with adsorption*, but that after periods of (active-inactive) oxidation the sludge becomes so (well-poorly) oxidized that its density is not materially changed by slight variations in the adsorption-oxidation balance.

Much has been said with regard to the deleterious affect of oil in the sewage and it has frequently been given as one of the causes of bulking. Frequent discharges of oil are received at the Salinas plant, and from the beginning it has been noticed that these discharges were often, *but not always* followed by severe bulking. It has now been established that there is *always* rise in the volatile content of the sludge following the receipt of oil discharges, but that, unless the ash content had already been falling for some time before the oil was received, serious bulking did not occur. Apparently the oil either increased adsorption or decreased oxidation, and so it has been found desirable to speed up oxidation by increasing the amount of air used for a few hours immediately after the oil was received. If all fats have the same effect, then the extremely high fat content, 340 p. p. m. of the Salinas sewage may be one of the principal reasons such large amounts of air are required at Salinas.

It has been stated that, at Salinas, *sphaerotilus* is always present in the sludge during severe bulking. The question naturally arises as to whether this organism is an indicator of a condition or whether it actually causes bulking. The development of this organism has often been attributed to the presence of sugars, dextrose, lactose or maltose, in the sewage.[5,6,7,8] However the writer agrees with Donaldson[9] that sugars are not essential to the development of these growths. *Sphaerotilus* is a characteristic sewage organism commonly found in sewage polluted streams. A logical view is that the sludge is being seeded continuously with these organisms from the incoming sewage, but that excessive growths develop only under certain environmental conditions. Apparently a sludge in which biological oxidation has been lagging behind adsorption for some time is an ideal medium for their rapid development, while if oxidation is keeping pace with adsorption they can gain little foothold and if it exceeds adsorption they are killed off quite rapidly. (Continued aeration of the sludge for three to six days with the addition of little or no sewage either eliminates or greatly reduces the number of organisms at Salinas, Des Plaines[8] and Decatur.[7]) Because of their high oxygen requirements sugars upset the adsorption-oxidation balance and, if the air supply or aeration period is not increased, oxidation will lag behind adsorption and a rapid growth of *sphaerotilus* will follow; any other organic waste, including additional domestic sewage, might have the same affect.

It is evident, therefore, that the first appearance of these organisms in the sludge is an indication of a condition, but it is believed that their presence

usually causes additional bulking and hence they may be a secondary cause of bulking. Their presence also increases the oxygen demand of the sludge, at least that appears to be the case at Salinas.

Once these organisms become established in the sludge it is necessary to know the best means of eliminating them. As previously stated they may be eliminated by bypassing most of the sewage and aerating the sludge for three to six days, but this is a very unsatisfactory method. In Run C an attempt was made to overcome the organisms by greatly increasing the amount of air used, without materially decreasing the amount of sewage treated. On the last two days of the run the dissolved solids in the mixed liquor increased slightly and gasification became sufficiently developed so that the sludge rose in the graduates, but the ash content and the density of the sludge continued to decrease. It is possible that if the run had been continued the organisms would have been overcome eventually, but because of the danger of losing most of our sludge, by having it pass over with the effluent, the run was stopped. However, there were still many *sphaerotilus* in the sludge at the start of Run D and these were successfully overcome. Donaldson[3] reports that at Tenafly the application of sufficient lime to the inlets of the aerators to bring the pH at their outlets up to 8.6 to 8.8 for six to twelve hours eliminates the organisms, but if insufficient lime is used or the application is not started soon enough the treatment is unsuccessful. Too much lime caused poor clarification. Morgan and Beck[5] report similar results at Des Plaines. It appears that after the organisms have gained a foothold the application of large amounts of lime is a better method of eliminating them than is a greatly increased air supply; it does not follow, however, that the use of lime should be relied upon instead of either increasing the air supply or the aeration period sufficiently to prevent the development of these organisms. The latter procedure will give a much better effluent, and Salinas experiences indicate that not nearly as much air is required to prevent the development of these organisms as is required to eliminate them after they have gained a foothold.

To reiterate, the primary cause of bulking appears to be insufficient biological oxidation to keep pace with adsorption, although oil discharges or the development of filamentous growths within the sludge may be contributing or secondary causes. If the sludge is in good shape to start with, the amount of adsorption will be primarily dependent upon the amount and character of the sewage treated, while the amount of oxidation will be dependent upon the amount of air used and the length of the aeration and reaeration periods. Since oxidation is a biological process the temperature and hydrogen-ion concentration also affect it in all probability, although neither of these are subject to sufficient variation at Salinas to be of much practical importance. To prevent bulking, at Salinas

at least, it is only necessary to regulate the amount of air used so that the dissolved solids in the mixed liquor are maintained as high or slightly higher than those in the sewage and the ash content of the return sludge as determined daily at a given hour is not subject to a continuous decline. If sufficient air is not available to do this, then all the air available should be used and the amount of sewage treated should be varied as necessary to maintain the above conditions. The ash content of the sludge should be determined early in the morning because the character and quantity of the low night sewage flow is probably subject to less variation than the character and quantity of the peak flow. It will be noted that no mention of rate of gasification was made in the above procedure for the prevention of bulking; it is believed that if the dissolved solids in the mixed liquor are held equal to or above those in the sewage, and long continuous declines in ash content of the sludge are avoided, gasification will always be well defined, at least at the sewage temperatures encountered at Salinas, 16–24° C.

Clarification.—The following observations on the clarifying action of different sludges have been made at Salinas:

1. A bulked sludge produces a clearer effluent than does a dense sludge. When the sludge was very badly bulked, but before it passed over the clarifier weirs, an extremely clear effluent, free from almost all suspended matter, was produced. This is probably due to the character of the floc in a bulked sludge. In such a sludge the large, expanded, slimy, floc probably entraps some suspended matter that is not so readily swept out by the more dense, compact, floc; then, too, adsorption is a function of the area rather than the weight of the floc and a given weight of bulked sludge may present a larger area for adsorption than does the same weight of a dense sludge. A contributing factor may be the depth of sludge carried in the final clarifiers. When the sludge was badly bulked at Salinas deep blankets of sludge were carried in the settlers. This sludge accumulation probably acted as a filter for the incoming mixed liquor which was directed downward by the inlet baffles and then rose up through the deep sludge blanket to the effluent weirs.

2. After periods of prolonged aeration the suspended solids removal was poor and the effluent frequently appeared somewhat turbid. This may have been due to (*a*) the absence of large numbers of active protozoa; Cramer[10] considers protozoa essential to clarification and Ardern and Lockett[11] state that their presence may facilitate clarification: (*b*) the very active gasification prevailing at that time; during active gasification some chunks of sludge come up on the final settlers: (*c*) the mechanical breaking up of some of the floc into very finely divided particles that did not settle out.

These observations and the general impression gained from the daily

appearance of the effluent have led to the conclusion that over-aeration, a continued rate of biological oxidation in excess of the rate of adsorption, may result in slightly impaired clarification. No turbidity tests have been made at Salinas, however.

Amount of Sludge Carried and Necessity of Maintaining Nitrification.—It has been repeatedly proven, both in the laboratory and in plant operation, by many investigators that increases or decreases in the amount of sludge carried increase or decrease the air requirements. The work of Grant, Hurwitz and Mohlman[4] confirmed this fact and also showed that small amounts of sludge reduced the B. O. D. of the sewage almost as rapidly as larger amounts did. Therefore it was decided to use very small amounts of sludge in experimental Runs A to E, which were made primarily to determine the minimum air requirements at Salinas. Although the Salinas sewage is much stronger than the average sewage, only 0.11 to 0.14% suspended solids by weight were carried in the aerators although it is customary at most plants to carry 0.20 to 0.25% solids and some plants carry considerably more. It seems logical to believe that the less sludge carried the greater will be the amount of organic matter adsorbed by a given amount of sludge and hence the more intense must be the biological oxidation to maintain the proper adsorption-oxidation balance. This may explain why it has been found necessary to maintain rather complete nitrification to avoid sludge bulking at Salinas while many authorities report that nitrification is not essential.

It has been shown that biological oxidation may result in either or both, liquefaction or gasification of the adsorbed matter, and that apparently high nitrification is obtained only when gasification is well pronounced. It is possible, or even probable, that the flora and environmental conditions such as temperature, pH, dissolved oxygen, etc., may differ as greatly for these two phases of oxidation as they do for the corresponding two phases of anaerobic digestion. Perhaps if a large amount of activated sludge is carried in the aerators, liquefaction plus light or moderate gasification will suffice to oxidize the adsorbed organic matter, but if only a small amount of sludge is carried, liquefaction plus pronounced gasification are essential to avoid bulking, just as when large sludge digestion capacity is available liquefaction plus moderate gasification, such as is obtained at, say, 65° F. and pH 6.8, will suffice to digest the sludge received, but if the digestion capacity is small conditions must be made optimum for liquefaction plus the maximum gasification to avoid difficulties

Summary and Conclusions

The design and first twenty months of operation of the Salinas, California, activated-sludge plant have been described. During that brief period bulking, poor clarification and loss of nitrification, as well as some

good results have been encountered. The plant has been operated with and without sludge reaeration, with and without baffling the aerators and with varying amounts of sludge and air. The following conclusions have been drawn from the Salinas experiences and current literature:

1. There is considerable short circuiting in the ordinary spiral-flow aeration tanks; it appears that the incoming sewage and sludge follow a spiral course around a central core of nearly quiescent liquor. Increasing the surface velocity of the liquor increases the diameter of the central core and hence increases the amount of short circuiting. This condition is probably more serious in aerators in which the flowing-through channels are nearly square, and in which large volumes of air are used, than it is in normal aerators. Diagonal baffles so placed as to deflect part of the rising column of air and liquor toward the center of the tank are effective in reducing the diameter of the core and hence the amount of short circuiting. This would indicate that the practice of introducing the air through porous tubes placed several feet above the tank floor with vertical baffles extending down nearly to the floor so as to produce an air lift action, such as has been used at some recent plants, might favor the creation of a very large central core and hence severe short circuiting.

2. At Salinas the practice of sludge reaeration did not make it possible to reduce the amount of air used per gallon of sewage, but that practice together with the baffling of the aerators made it possible to treat about sixty per cent more sewage in the same tank capacity when using the same amount of air per gallon of sewage.

3. At Salinas it is necessary to use about 3.4 cu. ft. of air per gallon of sewage to avoid bulking. This high air requirement may be caused by the abnormally high fat content of the sewage as well as by its high oxygen demand and concentrated nature.

4. The Salinas experiences show that the hourly variations in amount of air used should be much less than those in the amount of sewage treated. When larger amounts of sludge are carried in the aerators the air should be supplied at a uniform rate throughout the day, but when smaller amounts of sludge are used some reduction may be made in the amount of air used during the low night flow of sewage.

5. It appears that in order to get the most good from the air used it should be divided between the various parts of the aeration and reaeration tanks in such proportions that there is an appreciable amount of dissolved oxygen in the reaeration tanks, some at the inlet of the aeration tanks, and a gradually increasing amount toward the outlet of the aerators.

6. The oxygen-demanding material in the sewage is adsorbed on the activated-sludge floc surfaces and then biologically oxidized. Oxidation may progress in two phases, liquefaction and gasification. The relation between the dissolved solids in the sewage and those in the mixed liquor

shows the progress of liquefaction, while the time required for the sludge in the mixed liquor to rise in suitable containers under semi-controlled conditions serves as a rough measure of gasification. Gasification appears to be more important than liquefaction in the oxidation of adsorbed nitrogenous matter. These two phases of biological oxidation may be depending upon different flora and require slightly different environmental conditions for optimum progress.

7. The balance between adsorption and biological oxidation within the sludge must be maintained. Excessive adsorption is the *primary* cause of bulking, while excessive oxidation results in poorer clarification. Variations in the ash content of the sludge serve as a rough measure of the balance between adsorption and oxidation; increasing ash content indicates an increase in oxidation over adsorption and vice versa. The density of the sludge tends to follow variations in its ash content.

8. Occasional discharges of oil in the sewage upset the adsorption-oxidation balance so that they are always accompanied by decreases in the ash content of the sludge, but they do not cause serious bulking unless the ash content of the sludge has been falling for some time previous to the receipt of the oil. Because of the deleterious affect of the oil on the adsorption-oxidation balance it is desirable to increase the amount of air used for a few hours after receiving the oil discharges.

9. *Sphaerotilus* growths in the sludge may be a *secondary* cause of bulking sludge. The sludge may be constantly seeded with these organisms, but unless oxidation lags behind adsorption for several days the sludge is not a suitable medium for their development. Sugars in the sewage may contribute, but are not essential, to their development. The application of large amounts of lime appears to be a better means of eliminating these organisms once they have gained a foothold than is prolonged aeration or greatly increased amounts of air, but it does not follow that it should be relied upon instead of either increasing the air supply or the aeration period sufficiently to prevent the development of the organisms in the first place. Much less air is required to prevent the development of the organisms than is required to eliminate them after they have developed within the sludge.

10. At Salinas bulking may be avoided by regulating the amount of air used so that the dissolved solids in the mixed liquor are maintained slightly higher than, or equal to, those in the sewage; likewise the ash content of the sludge, as determined daily at a given hour, should not be subject to a continuous decline.

11. A preponderance of flaggellates over ciliates in the sludge may indicate a poor sludge, as is claimed by many investigators, but, at Salinas at least, a preponderance of ciliates over flagellates does not necessarily indicate a good sludge.

12. The Salinas experiences show that it is not necessary to carry large amounts of sludge in the aerators in order to produce a well purified, stable effluent. The use of small amounts of sludge make possible a saving in air required, but makes necessary the maintenance of very active biological oxidation processes which apparently entails rather complete nitrification.

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Sewage Filtration and Incineration of Sludge*

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Under an agreement with the International Sanitation Engineers, Inc., experimental units were built for the purpose of determining the effectiveness of coke and slag filters in filtering raw sewage and the possibility of incinerating the sludge adhering to the filter medium. The first experimental units were constructed in December, 1930. The original units were modified and replaced until tanks were devised which promised best and most economical results. The experimentation lasted for an entire year. All tests on the experimental units were made at the Plainfield, N. J., Joint Sewage Disposal Plant. This plant receives a domestic sewage, rather strong, somewhat stale and difficult to treat.

Coke Filters

The coke filters consisted of four units in series, each unit formed by a tank 18 by 22 by 56 inches. The sewage entered through an outer influent compartment, through an opening in the side at the bottom of the tanks, and flowed up through the filter material and thence out over an effluent weir extending across the entire side of the tanks. The working tank volume below the effluent weir was approximately 6 cu. ft. for each tank. Screened sewage was pumped at a rate of 2000 to 3000 gallons per hour to an adjustable weir box for the control of the desired flow. Three of the tanks were filled with pea-size coke containing a considerable amount of fine material, consequently the medium was very non-uniform in character. A portion of the coke was thoroughly screened over a $^1/_2$ in. screen and the fine material used to fill the fourth unit. Approximately 165 lb. of coke was required to fill each tank.

Sewage was applied to the units at a rate of 625 gallons per hour. Samples were taken every hour from the sewage and effluents of the different tanks. These samples were composited for the day and analyses made to determine suspended solids, B. O. D. and *B. coli*. After the coke had become saturated with sludge (fouled) it was found that operation had to be stopped to drain the tanks and remove the coke. The sewage solids clogged the beds rapidly and after two days a noticeable decline in suspended solids removal and B. O. D. reduction occurred. After 5 days of operation the sludge adhering to the coke, calculated on a dry basis, was 7.7 per cent. This sludge represented a potential heat value of 576 B. t. u. per pound of dry material removed from the filters. The material removed was practically inodorous and remained so for extended periods of time.

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The tests on the effluents showed that most of the suspended solids and B. O. D. removal took place in the first two tanks. With an average of 336 p. p. m. suspended solids and 326 p. p. m. B. O. D. in the screened sewage, the reductions amounted to 65 and 50 per cent, respectively. No *B. coli* removal took place.

Size of Coke

An effort was made to determine the value of larger sizes of coke for filter medium. The size used was so-called "nut coke." The same units were used as before but a small upright conveyor was placed in the influent compartment of the first unit in order to remove the coke and sludge. Sewage was passed through the filters at a rate of 1500 gallons per hour. The results obtained after a few weeks of operation showed that the suspended solids decreased from approximately 350 p. p. m. to 80 p. p. m. (77%) after passing through 22 cu. ft. of coke, and were reduced to 70 p. p. m. (80%) on passing through 36 cu. ft. of coke. The B. O. D. reduction amounted to 56% through 22 cu. ft. of coke and 63% through 36 cu. ft. of coke. With weaker sewage there was a greater percentage reduction. Operation of the conveyor proved unsuccessful, as it had a tendency to jam and often continuous operation even impeded the sewage flow.

Reduction of the flow increased suspended solids removal and B. O. D. reduction somewhat, but not commensurate with the reduced flow. All results of tests for *B. coli* removal were irregular, giving a final mean of 29.4% reduction. It was evident that the coke filters would not remove large percentages of *B. coli* unless the sewage was treated with a coagulant.

Experiments with larger sizes of coke produced both under high and low temperature conditions, with different flows, showed that with continuous operation the percentage removal of suspended solids and B. O. D. remained fairly constant.

Absorptive Properties of Coke

If coke had adsorptive properties in treating sewage we would expect some difference in the degree of purification by the different cokes. The high temperature coke contains a higher percentage of pure carbon and it might therefore have increased absorptive properties. The removal of the volatile constituents of the high temperature coke results in a greater amount of pore space, as evidenced by the lower specific gravity.

Results of experiments showed that absorptive properties of the coke medium for sludge or finely divided sewage solids were of minor importance, if present at all. Probably the only material adsorbed or absorbed by the coke was water and gases and some colloidal material. It was found that it was impossible for particles larger than of colloidal size to enter the pore space of the coke. The mechanism of suspended solids removal seemed to be a purely mechanical surface action. Although the

surface of the high temperature coke was more irregular and angular than that of low temperature coke, there did not seem to be any benefit to be derived from the increased roughness of the surface. These considerations led to the conclusion that commensurate results would be obtained by using slag as a filtering medium.

Velocity Studies

A study of the velocity of flow of sewage through the filtering medium was made by the use of a specially constructed tank of 11 cu. ft. capacity, with an influent compartment separate from a conveyor compartment. The conveyor partially supported the body of the coke since it passed under the body of the coke at an angle from the vertical side.

It was considered that three different factors could play a rôle, namely:

1. The per cent of voids.
2. The area of the surface of the medium.
3. The volume of voids and the number of voids.

Experiments conducted by us on different media and a medium of different sizes indicated that the percentage of voids was practically alike in all media within sizes which could be used for filtering. The volume and number of voids are related to the area of surface and when the size of the material decreases with an increase in numbers of voids, the voids become so small that danger of clogging occurs.

Condensed average results of 5-day runs through 11 ft. of filtering material were as follows:

Flow per Hour Gallons	Suspended Solids		B. O. D.		*B. Coli*
	P. p. m.	% Red.	P. p. m.	% Red.	% Red.
500	345	68.5	354	59.0	43.5
1500	376	73.5	370	57.5	38.0
2250	361	38.4	375	54.3	+19.4

The filters were operated each day for 10-hour periods. The sewage is about 6 hours old before reaching the plant, so that during the morning hours part of the night sewage was treated. The results showed that rates of application of more than 1500 gallons per hour through the eleven cubic feet of filtering material resulted in less removal of suspended solids and a gradual decline in B. O. D. reduction. *B. coli* reduction was irregular from day to day.

Fluctuations in Head

Variations in head on the different filter units and different media were determined throughout all experiments. No great variation occurred and it was found that the head built up gradually from 1 to 8 inches in the different tanks, becoming practically stationary. It was found that the

building up of head of sewage was a convenient method to determine when tanks should be taken off to be replaced by clean material.

Sludge and Moisture Content

Whenever tanks were taken off for replacement of the fouled material, analyses of the sludge were made. The sludge content in the sludge and coke mixtures varied from 7.6 to 10.3% on the dry basis, while the moisture in the mixture varied from 39.9 to 54.5 per cent. The moisture content of the cleaned coke varied from 23 to 30% depending upon the type of coke used.

Difficulties

Difficulties were encountered in the use of coke, principally because it would take time for the coke to be thoroughly water-logged and prevent floating. In order to overcome this feature more coke had to be placed in the tanks than was required for the filtering action, so that the mass would be held down. A second factor was the abrasion of the coke, making it necessary to replace a comparatively large percentage when re-used. A third source of difficulty was the non-uniformity of the coke, which made mechanical removal more difficult.

Slag Filters

On account of the difficulties encountered with coke as a medium for the filters, the filtering material was changed to slag known as $1^1/_2$-inch commercial size. There was considerable variation in size, running from pieces of $^1/_2$ inch to 2 inches and over. Sewage was passed through these filters at varying rates. After some preliminary runs, tests were made to determine the filter area and depth required for various rates of flow of sewage. Earlier tests were made on filters having variable cross-sectional areas throughout their depth. A new filter was constructed with a constant cross-sectional area throughout its depth. The filter used for the experiments on the rate of flow and its relation to depth was cylindrical in shape, about 8 ft. deep. A perforated plate was placed near the bottom, through which the influent passed and the effluent ran out of a 2-inch pipe placed 7 ft. above the perforated plate, giving a total filtering depth of 7 feet.

It had been determined previously that during continuous operation of the filter no falling off or increase in purification took place before the filters began to clog. The filter was operated starting with a low flow and increasing the rate of application.

Sewage was applied to the filter successively at the rates of 7500, 10,000, 12,500 and 15,000 gallons per day, corresponding to rates of application of, respectively, 104, 139, 173 and 208 million gallons per acre per day. Samples were taken every hour and composited for 6-hour periods. Runs of the

different flows were continued for periods of one week. A summary of the results obtained is given in Table I.

TABLE I

SUMMARY OF RESULTS ON RELATION OF RATE OF SEWAGE FLOW AND DEPTH OF FILTER (FILTER 7 FT.)

Rate, M. g. a. d.	Suspended Solids Infl., P. p. m.	Effl., P. p. m.	Reduction, %	B. O. D. Infl., P. p. m.	Effl., P. p. m.	Reduction, %
104	380	87	77.0	421	160	62.0
139	612	188	70.6	440	220	52.3
173	484	201	57.5	735	290	60.5
208	570	242	57.5	487	268	45.0

Examination of the results shows that as the rate of application was increased to 139, 173 and 208 m. g. a. d. satisfactory purification did not take place in one filter of 7 ft. in depth.

For the purpose of securing greater depth for the higher flows another

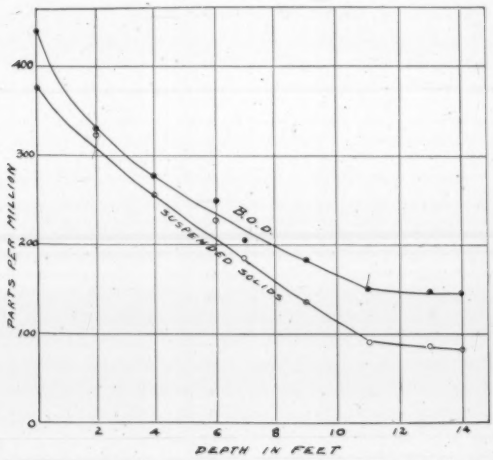


FIG. 1.—Relation of Suspended Solids and B. O. D. Remaining and Depth of Filter.

tank of the same design was placed in series with the first tank. For these experiments the first tank was filled with $1^1/_2$-inch slag and the second with $^3/_4$-inch slag. The tanks were equipped with sampling pipes at 2 ft. intervals. Runs were made for periods of one week to 10 days. The results showed that 6 ft. depth was sufficient for a rate of 70 m. g. a. d., 9 ft. for

104, 11 ft. for 139 and 14 ft. for 173 m. g. a. d. At the rate of 208 m. g. a. d. currents were set up in the filter which did not allow greater degrees of suspended solids removal and B. O. D. reduction. The reduction in suspended solids and B. O. D. is graphically shown for different levels at a flow of 139 m. g. a. d. in Figure 1. The relation between suspended solids removal and B. O. D. reduction is well shown. With more than 11 ft. depth of filter no further reductions took place. The points showing the greatest removal of suspended solids and B. O. D. reduction have been taken and given in Table II. Expressing the rates of application differently, the flow at a rate of 70 m. g. a. d. amounted to 265 gallons per day per cu. ft. of filter material, while at a rate of 173 m. g. a. d. 360 gallons per day per cu. ft. were applied.

TABLE II

EFFECT OF FILTER DEPTH

Depth, Ft.	Rate, M. g. a. d.	Suspended Solids			B. O. D.		
		Infl., P. p. m.	Effl., P. p. m.	Reduction, %	Infl., P. p. m.	Effl., P. p. m.	Reduction, %
6	70	355	105	70.4	378	182	52.0
9	104	364	89	74.8	420	155	63.0
11	139	375	93	75.2	431	152	64.7
14	173	400	94	76.5	582	143	75.4
14	208	350	119	66.0	466	176	62.2

Continuous Operation

After obtaining considerable data on the relation of the degree of purification to the depth of filter and the rate of application of sewage, two new groups of tanks were constructed with three filters in each group at a higher elevation. The first group of these tanks was designed as the primary group, receiving the sewage in coarse slag; the second group received the effluent of the primary group and was filled with fine slag. Each separate filter had a constant cross-sectional area throughout its depth of 2.6 sq. ft., after subtracting that portion of the area taken up by the influent compartment. The tanks were 3.5 ft. deep from effluent opening to the top of the screen upon which the slag rested. The weights of the slag were determined. During operation four tanks were run in series, that is, two of the primary and two of the secondary tanks. This left one tank in each group for emptying and refilling. The tanks were kept in operation continuously When a tank failed to remove sufficient quantities of solids the standby tank was switched in and the fouled tank taken out. The contents of the fouled tanks were removed and weighed after a drainage period of approximately 12 hours. The clean tanks were always in operation as the second or final tank of each group, so that partially fouled tanks became the first in each group.

Hourly samples were taken of the screened sewage and effluent of each

tank. The flows applied were first 12,500 gallons per day or a rate of 208 m. g. a. d. to each filter. After one week of operation the flow was reduced to 7500 gallons daily or a rate of 125 m. g. a. d. for each filter. The average results for the periods of experimentation were as follows:

Flow, M. g. a. d.	Suspended Solids Infl., P. p. m.	Suspended Solids Effl., P. p. m.	Suspended Solids Reduction, %	B. O. D. Infl., P. p. m.	B. O. D. Effl., P. p. m.	B. O. D. Reduction, %
125	348	95	72.7	358	161	55
208	228	114	50.0	258	119	46.0

The results were considered unsatisfactory and a change in method of operation made.

Change in Operation

The flow of sewage was reduced, the depth of the slag layer decreased to 2 ft. allowing $1^1/_2$ ft. of water layer on top, and the velocity of the sewage entering the channel and weir box was increased to prevent settling of material. Until that time screened sewage had been applied and during preliminary tests raw sewage was pumped to the tanks. The primary tanks were filled with a mixture of $1^1/_2$-inch and $^3/_4$-inch slag and the secondary tanks with $^3/_4$-inch slag. Two tanks were run in series as the primary unit and two more in series as the secondary unit. Raw sewage was treated at a constant rate of flow of 5000 gallons per day, the plant running continuously. To conform with actual plant operation and fluctuation in flow the raw sewage was treated at a rate of 7000 gallons per day during the time of greatest flow at the Plainfield plant, namely, from 12 noon to 4 A.M., and at 3500 gallons per day from 4 A.M. to 12 noon. Hourly samples were taken and composited for each rate of flow. The average results for a 10 days' continuous run for each of the four tanks in series was as follows:

	Susp. Solids, P. p. m.	Removal, %	Solids Retained, %	Moisture, %
Influent	299	..		
Tank 1	164	45	6.8	16.2
2	121	60	3.8	20.2
3	104	65	11.0	14.5
4	104	65	2.2	21.5

Each tank contained 300 lbs. of slag.

The results obtained showed that a shallow layer of slag with a water layer on top was more effective than deep layers of slag. The sludge content of the fouled material in the first tank could be brought rapidly to a desired concentration for incineration.

Reverse Rotation

The filters were then operated in a manner which might be called reversed operation, that is, after fouling clean filters to the extent of about 8 per cent with sewage solids (on a dry basis) they were then operated as

secondary tanks and preceded by a clean filter. Experimental work had previously demonstrated that coarse screened sewage could be very well filtered through larger slag ($1^1/_2$ inch), which, according to the engineer running the incinerator, resulted in considerable economies. The coarser slag allowed operation at a very low head and prevented clogging of the

TABLE III

SERIES OPERATION OF SLAG FILTER AT TWO RATES OF FLOW

		Day (12 M.–4 A.M.)				Night (4 A.M.–12 M)				
Date	Tank No.	Flow, M. g. a. d.	Susp. Solids, P. p. m.	Reduction, %	Solids Deposited, Lb.	Flow, M. g. a. d.	Susp. Solids, P. p. m.	Reduction, %	Solids Deposited, Lb.	Cumulative Dry Solids, Lb.
Oct. 27	Infl.	109	416	..	..	54.5	192	..	..	...
	1		248	40.4	6.5		104	45.8	0.86	7.36
	2		176	57.6	2.8		87	54.7	0.12	2.92
	3		117	71.8	2.3		61	68.0	0.25	2.55
	4		81	80.5	1.4		67	65.0	..	1.34
Oct. 28	Infl.	109	424	..	..	54.5	186	..	..	...
	1		236	44.4	7.3		170	8.6	0.16	14.82
	2		176	58.5	2.33		109	42.0	0.59	5.74
	3		134	68.4	1.63		85	54.3	0.23	4.41
	4		115	72.7	0.74		58	68.7	0.26	2.34
Oct. 29	Infl.	109	384	..	..	54.5	214	..	..	...
	1		244	36.5	5.4		162	24.3	0.51	20.73
	2		160	58.3	3.3		106	50.4	0.55	9.59
	3		115	70.0	1.7		76	64.5	0.30	6.41
	4		79	79.5	1.4		57	73.3	0.20	4.0
Oct. 30	Infl.	109	378	..	..	54.5	170	..	..	...
	1		226	40.0	5.9		94	45.0	0.74	27.57
	2		196	48.0	1.16		69	59.0	0.24	10.99
	3		147	61.0	1.9		53	69.0	0.24	8.5
	4		129	66.0	0.7		51	70.0	..	4.7
Oct. 31	Infl.	77	466	..	..	77	174	..	..	...
	1		168	64.0	8.2		220	−26.4	..	35.17
	2		120	74.0	1.3		80	54.0	1.4	13.69
	3		104	77.5	0.4		57	67.0	0.2	9.1
	4		97	79.0	0.2		46	73.5	0.1	5.0
Nov. 1	Infl.	77	320	..	..	77	240	..	..	...
	1		98	70.5	6.5		94	61.0	1.4	43.1
	2		84	73.5	0.4		80	67.0	0.13	14.2
	3		76	76.0	0.7		58	76.0	0.2	10.0
	4		64	80.0	0.4		46	81.0	0.1	5.5

filters. By subjecting the clean filter to the raw sewage it is fouled rapidly, and the sludge blanket thus formed aids in removing the finer solids when it is operated as a secondary filter.

The tanks used for the following experiments had a cross-sectional area of 2.6 sq. ft. and a total depth of 6 ft. The effluent run-arounds were at the height of 3.5 ft. above the bottom of the tanks, while the grate was raised from the floor so that the total filter depth was 3 feet. The filters

were operated continuously to conform with actual rates of flow. The rate of application during the day was 109 million gallons per acre per day and during the night 54.5 m. g. a. d.

Results showing suspended solids reduction and solids deposition in the slag, including some days at reduced day flows, are given in Table III. The results represent the period before it became necessary to take the first tanks off, on account of fouling. The average reduction in suspended solids for the day flows at 109 m. g. a. d. was 74.7% and at a continuous rate of 77 m. g. a. d. 78%, while at a reduced flow with weaker sewage the reduction amounted to 69.2 per cent.

Running the experimental plant continuously for 10 days with a flow of 70 m. g. a. d. gave the following results:

	Suspended Solids, P. p. m.	Reduction, %	Solids Deposited, Lb.
Influent	322	..	..
Tank 1	195	39.5	50.9
2	166	48.5	12.4
3	129	60.0	12.5
4	89	72.0	10.0

It appears therefore that the filters were not much influenced by flows varying from 55 to 109 m. g. a. d.

Using partially fouled tanks as secondary and clean tanks as primary tanks, the rate of application was increased to 156 m. g. a. d. The purpose of this test was to determine whether the filters could stand a temporary overload without disturbing the process of filtration. The two partly fouled tanks showed an average suspended solids removal of 60.4%, with an additional 10.2% in the secondary tanks, or a total of 70.6 per cent.

Operation with Two Tanks

Previous work done showed the possibility of using only two tanks for filtering instead of four. The filters were operated as before, namely, using a partially fouled tank as the first unit. Tanks A and B were operated in series. Tank A was filled with a 2-ft. layer of $1^1/_2$- and $^3/_4$-in. slag mixed, while Tank B was filled with $^3/_4$-in. slag. Since it was necessary to foul A before the rotation began, B was added merely to obtain some information as to the action of fine slag in the second tank. The flow during the first seven consecutive daily runs was the same as with the four filters, namely, 109 m. g. a. d. for the day sewage and 54.5 m. g. a. d. for the night sewage. Samples were collected every hour and composited for the 12-hour periods. The flow was increased, after the tanks were fouled, to a rate of 156 m. g. a. d. after the seventh consecutive day of operation. Tank 3 was put into operation on the 11th day, filled with 300 lb. of $1^1/_2$-in. slag. In addition, the layer of water above the slag was increased to 2.5 ft.

The results obtained are shown in Table IV. Allowing Tank A to remain on as a third tank gave little improvement in suspended solids reduction, despite the increase in flow. We were led to believe that seventy per cent removal or slightly better was the best to be expected by this method of operation.

TABLE IV

OPERATION WITH TWO TANKS AND DIFFERENT FLOWS

		Day Sewage			Night Sewage		
Days	Tank No.	Flow, M. g. a. d.	Susp. Solids, P. p. m.	Reduction, %	Flow, M. g. a. d.	Susp. Solids, P. p. m.	Reduction, %	Sludge Deposited, Lb.
1	Inf.	109	398	..	54.5	196	..	..
	A		138	65		76	61	8.4
	B		128	68		65	67	0.4
2	Inf.		392	..		244	..	..
	A		150	62		68	72	16.8
	B		115	71		66	73	1.4
3	Inf.		392	..		228	..	..
	A		146	63		98	57	25.0
	B		105	73		64	72	2.8
4	Inf.		412	..		216	..	..
	1		178	57		86	60	7.8
	A		72	82		57	74	28.2
5	Inf.		478	..		210	..	..
	1		180	62		80	62	17.4
	A		140	71		65	69	29.4
6	Inf.		418	..		222	..	..
	1		190	55		84	63	25.0
	A		136	68		67	70	32.1
7	Inf.		512	..		200	..	..
	1		224	56		90	55	34.1
	A		114	73		68	66	34.3
8	Inf.	156	388	..		188	..	..
	1		198	49		186	1	41.4
	A		147	62		80	58	37.3
9	Inf.		432	..		222	..	..
	1		226	48		89	60	50.7
	A		244	44		63	72	36.7
10	Inf.		364	..		268	..	..
	1		262	28		258	3	54.8
	A		208	43		65	76	40.7
11	Inf.		368	..		196	..	..
	3		216	42		94	52	6.9
	1		192	48		115	41	55.8
	A		136	63		130	34	42.8
12	Inf.	156	390	..		244	..	..
	3		184	53		112	54	16.2
	1		152	61		96	61	57.2
	A		134	65		86	65	43.5

TABLE IV (*Continued*)

Days	Tank No.	Day Sewage Flow, M. g. a. d.	Day Sewage Susp. Solids, P. p. m.	Day Sewage Reduction, %	Night Sewage Flow, M. g. a. d.	Night Sewage Susp. Solids, P. p. m.	Night Sewage Reduction, %	Sludge Deposited, Lb.
13	Inf.		394	..		184	..	..
	3		214	46		88	52	24.1
	1		138	65		72	61	60.3
	A		107	73		88	52	44.5
14	Inf.		432	..		288	..	..
	3		210	50		118	59	34.0
	1		159	62		91	68	62.6
	A		128	70		72	75	45.9
15	Inf.		428	..				..
	3		200	53				42.8
	1		160	63				47.4

Effect of Size of Slag

In order to study the effect of size of slag, with two tanks in so-called reversed rotation, Tanks A and B were each filled with 300 lb. of 1½-in. slag and operated at flows of 218 m. g. a. d. for the day sewage and 109 m. g. a. d. for the night sewage. Tank A was partially fouled in two days, before Tank B was started in operation. The results of a short run are shown in Table V. The larger flow reduced the percentage removal of suspended solids in the primary tank by about 10 per cent and affected the secondary tanks even more. The removals were also quite variable. However, the test showed in this case, also, that the filters could stand a

TABLE V

EFFECT OF SIZE OF SLAG WITH HIGH FLOWS

Days	Tank	Day Sewage Flow, M. g. a. d.	Day Sewage Susp. Solids, P. p. m.	Day Sewage Reduction, %	Night Sewage Flow, M. g. a. d.	Night Sewage Susp. Solids, P. p. m.	Night Sewage Reduction, %	Sludge Retained, Lb.
1	Inf.	140	494	..	110	216	..	..
	A		227	54		133	38	15.9
2	Inf.		450	..		280	..	..
	A		274	39		100	64	28.1
3	Inf.		422	..		180	..	..
	A		208	51		72	60	13.4
	B		168	60		72	60	30.3
4	Inf.		376	..		224	..	..
	A		236	37		100	55	23.0
	B		208	45		96	57	32.0
5	Inf.		564	..		190	..	..
	A		258	54		145	24	40.6
	B		213	62		100	47	34.9
6	Inf.		370	..				..
	A		186	50				50.8
	B		168	55				35.9

temporary overloading when two filters were used in series filled with a shallow layer of coarse slag.

Increasing the slag layer by 25% (400 lb. per tank), or 2.5 ft. depth with a layer of water of 2.5 ft. on top, and flows of 109 m. g. a. d. for the day sewage and 54.5 m. g. a. d. for the night sewage, showed in a 9-day consecutive run that the primary tank removed on an average slightly over 60% of the suspended solids and the secondary tank an additional 10%, corresponding very closely to the test made previously.

Filtering of Activated Sludge

In order to determine the practicability of retaining activated sludge in the filters when mixed with raw sewage, a brief experiment was run. To the coarse screened sewage an additional 200 p. p. m. of activated sludge was added. The results obtained on suspended solids were as follows:

	Sewage	Sewage and Activated Sludge
Influent, P. p. m.	530	705
Effluent, P. p. m.	152	152
Reduction, %	71.5	78.5

The additional load due to the activated sludge did not affect the final effluent.

Effect of Chemicals

The general results of previous studies showed that if strong sewage of from 400 to 500 p. p. m. suspended solids was treated, the suspended solids in the effluent would be about 140 p. p. m., whereas if sewage was treated averaging about 200 p. p. m. suspended solids, the effluent contained less than 65 p. p. m., with corresponding reductions in B. O. D.; *B. coli* removal was low and erratic. Evidently there were certain finely divided particles which were not retained in the filter.

The coagulating agents used were iron and aluminum salts. The time allotted for these experiments was limited and they were planned not with the idea of being extensive or comprehensive, but merely to gain some knowledge of the possibilities of applying chemical treatment to this process of sewage treatment. One of the tanks was used as a coagulating basin, giving a theoretical detention period of about 30 minutes.

Chemicals were added to the sewage just before it left the weir box, relying upon mixing to take place as the sewage passed through a 2-in. pipe to the bottom of the coagulation tank. Sewage was applied at a rate of 121 m. g. a. d. and passed through one tank. Samples were collected hourly, composited, and suspended solids, B. O. D. and *B. coli* determined. A condensed summary of a number of runs is given in Table VI. As previously pointed out, the Plainfield sewage is rather stale and contains comparatively large quantities of finely divided par-

TABLE VI

SUMMARY OF RESULTS—CHEMICAL TREATMENT

No.	Sewage	Suspended Solids, P. p. m.	% Red	B. O. D., P. p. m.	% Red.	*B. Coli* 1000 per Cc., P. p. m.	% Red.	pH	Treatment	Remarks
1	Inf.	375	..	386	..	250	..	7.4	60 P. p. m. $Fe_2(SO_4)_3$	Mod. stirring
	Effl.	42	89	74	81	95	62	6.7		
2	Inf.	393	..	370	..	950	..	7.4	60 P. p. m. $Fe_2(SO_4)_3$	Rapid stirring
	Effl.	53	87	73	80	95	90	6.8		
3	Inf.	345	..	300	..	150	..	7.5	60 P. p. m. $Fe_2(SO_4)_3$	Slow stirring
	Effl.	182	60	188	37	115	23	6.8		
4	Inf.	310	..	337	..	250	..	7.5	60 P. p. m. $Fe_2(SO_4)_3$	No stirring
	Effl.	210	32	242	28	250	0	6.8		
5	Inf.	286	..	450	..	450	..	7.4	60 P. p. m. $Fe_2(SO_4)_3$	Very rapid
	Effl.	107	62.5	86	81	250	45	6.7		
6A	Inf.	277	..	425	..	250	..	7.6	120 P. p. m. H_2SO_4 + 50 $FeCl_3$ (tech.)	
	Effl.	63	77	77	82	60	76	5.5		
6B	Inf.	372	..	433	..	700	..	7.5	100 P. p. m. H_2SO_4 + 40 $FeCl_3$ (tech.)	
	Effl.	200	46	218	50	250	64	5.8		
7A	Inf.	225	..	273	..	700	..	7.4	140 P. p. m. H_2SO_4 + 50 $Fe_2(SO_4)_3$	
	Effl.	24	89	36	87	25	93	5.2		
7B	Inf.	357	..	573	..	1100	..	7.4	140 P. p. m. H_2SO_4 + 40 $Fe_2(SO_4)_3$	
	Effl.	137	62	147	74	60	96	5.2		
8	Inf.	209	..	440	..	700	..	7.4	50 P. p. m. $Al_2(SO_4)_3$ (tech.)	
	Effl.	166	20	170	61	700	0	7.0		
9	Inf.	160	..	155	..	700	..	7.5	30 P. p. m. $Al_2(SO_4)_3$ + 30 $Fe(SO_4)_3$ + 140 H_2SO_4	
	Effl.	86	46	75	52	10	28.5	5.0		

ticles. Best results were obtained with $Fe_2(SO_4)_3$ when the sewage was stirred by means of a paddle revolving at a rate of 10 revolutions per minute. On account of insufficient detention time in the small tank, fine floc particles passed over the weir in all cases.

Certain quantities of H_2SO_4 and ferric chloride or ferric sulphate produced good results when the final pH values were 5.5 or below. Clarification was complete but the floc formed was fine and not retained in the filter. When the effluent was allowed to settle for $^1/_2$ hour the supernatant was clear with from 5 to 10 p. p. m. suspended solids.

The amounts of H_2SO_4 to be added to the sewage vary with the total alkalinity; sufficient detention must be given to produce a well-clarified effluent.

Observations

Throughout the investigations it was noted that especially with reverse operation of the filters there was no floating material or scum in the effluent of each filter, in spite of the fact that considerable scum, consisting mostly of soap fats and débris, was present on the surface of the influent samples. During runs on Mondays and Tuesdays, when considerable laundry waste was received, this was especially noticeable.

Experiments were continued for about a year, including runs with the different filtering materials, changes in construction of tanks, etc. The absence of odors from the filters was frequently remarked upon. Only when tanks were left standing in the hot weather for 10 or more days hydrogen sulphide odors began to develop. With tanks regularly emptied in routine operation such long periods of standing or fouling did not occur. There are probably two reasons for the absence of odor. It has been demonstrated by one of us (1) that hydrogen sulphide production is very slow in sewage if the sewage is not inoculated with cultures of hydrogen sulphide producing organisms. Freshly collected sewage must stand several days before hydrogen sulphide production can be measured, but if the same sewage is inoculated with H_2S producing organisms, similar quantities are produced within a few hours. Sterilization of the filter medium by the high temperature in the incinerator is undoubtedly an important factor. The second possibility is that the odors are re-absorbed by the sludge adhering to the filter material. Laboratory experiments have shown that considerable quantities of gaseous H_2S added are readily absorbed by the sludge.

Sludge and Moisture Content

For the economical incineration of the sludge a certain minimum percentage of sludge must adhere to the slag. Throughout the investigation the quantity of sludge retained by the filters was determined and some results are included in Tables III to V. A summary of several tests, in

which the sewage was run through 2 to 2.5 ft. of slag by reversed rotation, is given in Table VII. The moisture content of the mixtures varied between 23 and 32 per cent. This moisture content will vary with the extent of drainage, but 25% moisture in the mixture would seem a low and safe figure for calculations when the mixture contains a sludge percentage of 8% on the basis of dry slag. It would appear possible to obtain this concentration rapidly. In calculating the cost of fuel and power the engineers used a 7% sludge content for basic figures, derived from sewage with an average suspended solids content of 200 p. p. m. and 70% retained in the filter.

TABLE VII

SLUDGE AND MOISTURE CONTENTS OF FILTER MATERIAL

Tanks on Days*	Depth of Slag, Ft.	Weight of Sludge, Lbs.	Moisture of Slag, %	Moisture of Fouled Mix, %	Dry Solids to Dry Slag, %
3–11	2	45.9	6.0	23	12.5
6–6	2	47.4	8.0	28	17.2
5	2	42.8	8.5	27	17.2
2–4	2	35.9	5.5	24	12.0
4	2	50.8	6.5	29.8	17.5
2–5	2.5	31.3	7.9	25	8.5
5–2	2.5	75.2	7.9	32	20.0

* 3–11 means 3 days as primary and 11 days as secondary tank.

Incineration

The building and operation of an experimental unit for the incineration of the sludge in the fouled filter material was done under supervision of Mr. S. F. Hay, Vice President of the Isbell-Porter Co., Newark, N. J.

The experimental unit was made up of two compartments connected by a passage for the removal of the hot gases. A fixed grate was built in the first compartment, upon which coal was burned to furnish heat required for the drying and burning of the material on the slag. The hot gases from this burning coal were drawn through a passage and thence under the grate upon which the charge of fouled slag was placed. After the gases had passed through the slag they were discharged into the atmosphere although it is proposed to use these gases for pre-drying (Figure 2). For experimental purposes and analyses samples of the gases were trapped and washed through water.

The unit required charges of from 250 to 300 pounds of sludge-coated slag. Since the small filters could not be fouled rapidly enough to supply sufficient material for a number of successive days of operation of the incinerator, mixtures were prepared of slag and sludge from the settling tanks at Plainfield. This sludge had concentrations of from 6 to 10% and a much higher moisture content than the materials from the fouled

filters, and was very odorous. During the drying operation a temperature of about 800° F. was maintained in the mixture for about 30 minutes. The temperature of the exit gases increased from 250° F. at the beginning of this period to 450° F. at the end of 30 minutes. After 30 minutes' drying the temperature under the slag was increased to about 1200° F. and maintained for 15 minutes. During this time the temperature of the exit gases increased from 550° to 700° F. These hot gases are to be used for predrying. The temperatures were regulated with various amounts of introduced air.

Water vapor and some unburned material (smoke) were emitted from

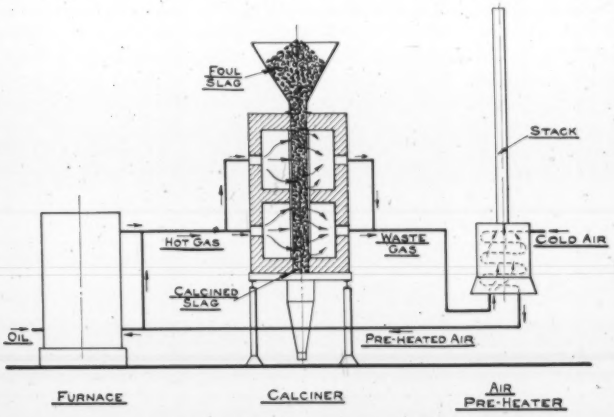


FIG. 2.—Diagram of Incineration Unit.

the unit during the first 20 minutes of the drying period. The putrefactive odors from the settling tank sludge—slag mixtures come off almost at once, and when diluted with air were not very concentrated or very noticeable. Charges of fouled slag obtained by filtration emitted considerably less volatile substances. The odor emitted resembled a burnt vegetable odor. This odor disappeared to a considerable extent when the temperature was increased at the latter part of the runs.

Analyses were made of the gases emitted and it was found that carbon monoxide, if present, was less than 0.1%, CO_2 ranged from 2 to 9.7%, oxygen from 9.5 to 19.7%. No combustible gases were present. Experiments were made to absorb the odor-producing substances in water, oil and water carrying activated carbon; the latter proved best. Most of the odors could be eliminated, but not entirely. This was probably due to the

high temperature of the exit gases and the operation of the unit as a batch process. Further experiments showed that when the temperature of the exit gases was reduced to below 400° F. odors were practically absent.

Charges weighing 325 pounds placed in a layer on the grate had a depth of about 9 inches. Several times spots of wet material at the center and top of the layer were found upon examination of the bed after the 30 minute drying period. This was evidently due to by-passing of the hot gases around the edges of the bed. A proposed incinerator feeds the mixtures continuously.

Loss of Slag

An attempt was made to determine the loss of slag during successive treatments in the incinerator. A weighed quantity of 1½-inch slag used was mixed with sludge and fired in the calciner. This process was repeated. After each firing the slag was screened over a half-inch screen and reweighed. The weight of slag remaining after each burning and the percentage loss are given in Table VIII. The loss of fines appears to be about 2% in each case. This loss was not entirely due to burning. The slag had to be mixed thoroughly with the sludge and some breakage was due to this handling. There was a slight increase in loss with the number of times the slag was subjected to heat.

TABLE VIII

LOSS OF SLAG ON CALCINING

Burnings No.	Weight of Slag, Lb.	Loss of Slag, Lb.	Loss, %
Start	498	.	...
1	498	0	0
2	490	8	1.6
3	482	8	1.7
4	473	9	1.8
5	463	10	2.2

Cost

The Isbell-Porter Co. of Newark, N. J., designed a layout of a plant of a million gallons average daily capacity with a maximum hourly rate of 1.5 m. g. d. The filters unit can be lifted and the fouled slag discharged into the calciner (Figure 3). A complete plant, including bar screen, grit chamber, filters, traveling crane, hoppers, hoist, drier and calciner, furnace and air pre-heater, stack, bucket elevator, storage for slag and screenings, building covering calciner and heater, tools, contingencies, etc., for the removal of 70% suspended solids and a reduction of 55–60% B. O. D. with double filtration is estimated by them to cost $110,000. A plant for 3 m. g. d. design capacity giving the same removals would cost $160,000. A plant for 1 m. g. d. average flow and maximum of 1.5 m. g. d. removing

60% suspended solids and 45–50% B. O. D. reduction would cost $90,000. For more complete treatment the cost of a mixing and final settling tank must be added.

Based upon an average sewage of 200 p. p. m. suspended solids with 70% removal, the above mentioned firm estimates the operating cost to be for fuel, power and supplies (including replacement of slag) $13.50 for a 1 m. g. d. plant. Labor in addition. It is estimated that about 150 gallons of fuel oil are required for the incineration of the sludge from one m. g. d. sewage when the slag is fouled to the extent of only 7 per cent.

If more complete treatment is required with chemicals to obtain a sus-

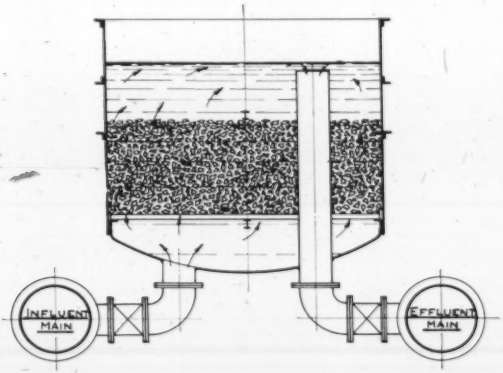


FIG. 3.—Filter Unit; 8 Feet in Diameter, 2.5 Ft. Slag, 6 Units per M. G. D.

pended solids removal of 85%, a B. O. D. reduction of 85% and 90 to 95% reduction in *B. coli* the cost for suitable chemicals amounting to $1.50–$2.00 is to be added to the above operating costs.

General Conclusions

After experimenting for about one year with different types of filter materials and different types of tanks, results show that filtering coarse screened sewage upward through commercial $1^1/_2$-inch slag is practical from a treatment standpoint. The results showed that about 70% suspended solids were removed and from 55 to 60% B. O. D. reduction took place, but no persistent reduction in *B. coli*, when four tanks containing 2.5 ft. of slag were used in reversed rotation, with an application of about 110 m. g. a. d. of sewage. With two tanks in reversed rotation, the same

depth of slag and same rate of application, about 60% suspended solids were removed and from 45 to 50% B. O. D. reduction took place.

For a higher degree of treatment (about 85% suspended solids reduction, 85% B. O. D. reduction and 95% *B. coli* reduction) suitable chemicals must be added.

Brief experiments on the addition of activated sludge showed that the activated floc when mixed with the sewage was retained by the filters.

Absence of odors from the filters was noticeable throughout the period of experimentation.

The slag and sludge mixtures were calcined and the sludge completely incinerated. Odors were emitted which could be controlled practically by the operation of the unit.

The loss of slag during calcining appeared to be about 2 per cent.

Cost estimates made by the Isbell-Porter Co. of Newark, N. J., for a plant with average flow of 1 m. g. d. and maximum hourly flow of 1.5 m. g. d. expected to remove 70% of the suspended solids and 55–60% B. O. D. reduction and incineration of the sludge was $110,000. A plant with units removing 60% suspended solids and 45–50% B. O. D. reduction was estimated to cost $90,000. Operating cost for treatment of 1 m. g. d. was estimated to be $13.50 exclusive of labor.

For more complete treatment additional cost for suitable chemicals must be added.

Reference

[1] W. H. Baumgartner, 1932, "Studies on Hydrogen Sulphide Formation in Sewage." *Ind. Eng. Chem.* (In press).

Sewage Works Operation

Proposed Disposal of Sewage Grit and Coarse and Fine Screenings by Incineration*

By Darwin W. Townsend

Principal Assistant Engineer, Milwaukee Sewerage Commission

The comparatively recent decision on the part of the Sewerage Commission of the City of Milwaukee to dispose of the sewage grit and screenings produced in its sewage treatment works is the culmination of a recommendation made as far back as the year 1926, which recommendation, because of an apparently unavoidable combination of various circumstances, could not be carried out until comparatively recently. The original recommendation, however, did not include the incineration of grit, the decision to incinerate this material in combination with the screenings having been contained in a recommendation of the present Chief Engineer late in the year 1931.

During the interim of approximately six years, these preliminary process materials have been removed from their immediate source of origin and deposited in piles at one end of the sewage disposal tract. These piles have reached such proportions that no more area is available for continuing this practice, which, from the time of its inception, was considered only a temporary expedient.

The 1926 recommendation contemplated the partial dehydration of the screenings in Worthington filter presses of the Berrigan type, followed by incineration of the dehydrated material in a commercial type of incinerator best adapted to the burning problem as it was understood at that time. Later, steps were taken toward attempting the burning of the dehydrated screenings in sludge-drying furnaces, two Berrigan presses having been provided and also mechanical facilities for feeding screenings into the furnaces. This method was abandoned after a reasonable trial period, for several reasons, primarily because of interference with the maintenance of uniform temperatures in the sludge driers, resulting in a decidedly inefficient operation of these units. Other difficulties, both manual and mechanical, were encountered in the feeding, pressing and subsequent handling of the dehydrated screenings. Pressing was therefore soon abandoned.

During 1927 study was given to the matter of disposal of screenings by

* *Presented before the Fifth Annual Meeting of the Central States Sewage Works Association, Rockford, Illinois, May 14, 1932.*

digestion, certain small-scale tests having indicated the desirability of conducting further tests upon a larger scale in order to determine, if possible, whether or not this method would be practical and feasible from an operating standpoint. The small-scale tests indicated rather conclusively that, under controlled conditions of pH and temperature, the process was feasible from a biological standpoint, it having been the apparent intent either to incorporate the digested material into the waste activated sludge and convert the combination of the two materials into a fertilizer base, or to dry the digested screenings upon sludge drying beds and dispose of the dried material ultimately either by incineration or by hauling it from the site of the plant for deposit on waste land.

A description of the screenings digestion plant which was subsequently designed and constructed, together with an outline of the analytical results obtained in the original small test units, is given in a paper presented by Dr. Willem Rudolfs and the writer before the American Society of Municipal Improvements at the Detroit convention in October, 1928.

After a period of operation approximating one and one-half years, during which time a wide range of temperature and pH control was investigated, and also during which time many changes relative to mechanical circulation, etc., were made in the equipment as originally installed, the experiment was abandoned, it having been concluded as far as the work had progressed that its application on a large scale was impracticable. Usually the termination of the several different sets of tests conducted was more or less automatic in principle, the digestion compartments having become so overburdened with materials of an undigestible character as to interfere seriously with the uniformity in the rate of gas production. In fact, as the tests progressed the rate of flow of gas from the tanks to the gasometers was so intermittent and at times so spasmodic as to render the process quite impracticable from the standpoint of being a self-contained heat balance proposition.

For several years past, the coarse sewage screenings, which are collected on bar screens, and which are relatively small in quantity, have been burned in one of the sludge-drying furnaces, the partial dehydration prior to burning having been accomplished for the first two or three years by use of a Coffin basket-type hydraulic press and later, as well as at the present time, by use of a Tolhurst centrifugal machine of the laundry type.

The several practical advantages present in the dehydration of coarse screenings in this centrifugal machine were of sufficient interest to warrant experiments upon its further application to the dewatering of the fine screenings. The tests subsequently conducted indicated the practicability of adapting this type of unit to the dewatering of all of the screenings and also the grit.

In the several tests conducted, each of the three materials was centri-

fuged separately and collectively, the proportions of the coarse and fine screenings and grit as combined and mixed having been adjusted to correspond with the proportional rate at which they are normally produced. These proportions for all practical purposes were about 14 per cent coarse screenings, 58 per cent fine screenings and 28 per cent grit, the balanced moisture percentage of the wet mixture having been about 81 per cent and that of the mixture after centrifuging about 65 per cent, the complete operation cycle having, during repeated tests, been accomplished in about 25 minutes.

The sewage treated at the Milwaukee Plant is for the greater part collected in a system of combined sewers. Coarse screenings, fine screenings and grit are collected at rates of 150 lb., 975 lb. and 325 lb., respectively, per million gallons, the respective moistures being 88, 92 and 55 per cent. After centrifuging, the above unit weights are 54 lb., 363 lb. and 243 lb., the respective corresponding moistures being 61, 78 and 40 per cent.

The above data show that the admixture noted, after centrifuging, will have about the following ultimate analysis by weight-water 65, combustible 21 and ash 14 per cent. From experience, observation and experiment, the forming of the following conclusions appears to be justified:

A. The water remaining in the material after centrifuging will be confined within the cellular structure of the material.

B. The combustibles will be for the most part volatile hydrocarbons, requiring apparently, for the most efficient degree of incineration, high temperatures and radiant heat exposure for a considerable part of the time, coupled with a considerable amount of excess air for complete combustion.

C. The resulting ash appears to be principally silica and somewhat highly acid at the higher combustion temperatures.

In the centrifuge tests it was found that the admixture of grit with the screenings assisted somewhat in the process by tending to reduce the actual centrifuging time. Any appreciable reduction in time required to obtain any given degree of moisture reduction is, of course, decidedly advantageous from the standpoint of total electric energy required for operating machines and also in reference to the total number of machines required. However, in this specific instance no appreciable reduction in either of these two items is to be anticipated. It may be reasoned that the tendency toward a decrease of centrifuging time can be attributed to the greater specific gravity of grit than that of the screenings, since the grit under the influence of the centrifugal force of the machine in motion acts in a manner tending to facilitate drainage.

The problem of selecting a type of incinerator suitable for burning material of this particular character gave considerable concern, and several incinerator installations were inspected, with the ultimate result that the type of unit as manufactured by the Morse Boulger Company, of New

TABLE I

FINE SCREENINGS TO BE INCINERATED

In Pounds per Day

	110 M. G. D.			1930	153.75 M. G. D.			1945	196.25 M. G. D.			1960
	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month
Wet material	83,600	107,250	61,820	114,730	116,850	144,906	86,407	160,361	149,150	191,344	110,292	204,689
Centrifuged mat.	31,020	39,930	22,990	41,360	43,357	55,811	32,134	57,810	55,342	71,239	41,016	73,790
Water to be evaporated	24,420	31,350	18,040	32,560	34,132	43,819	25,215	45,510	43,567	55,931	32,185	58,090
Ash	880	1,320	495	1,694	1,230	1,845	692	2,368	1,570	2,355	883	3,022
Volatile matter	5,720	7,260	4,455	7,106	7,995	10,147	6,227	9,932	10,205	12,952	7,948	12,678

COARSE SCREENINGS TO BE INCINERATED

In Pounds per Day

	110 M. G. D.			1930	153.75 M. G. D.			1945	196.25 M. G. D.			1960
	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month
Wet material	16,280	....	....	....	22,755	....	....	....	29,045	....	....	....
Centrifuged mat.	5,940	....	....	....	8,302	....	....	....	10,597	....	....	....
Water to be evaporated	3,960	....	....	....	5,535	....	....	....	7,065	....	....	....
Ash	330	....	....	....	461	....	....	....	589	....	....	....
Volatile matter	1,650	....	....	....	2,305	....	....	....	2,945	....	....	....

GRIT TO BE INCINERATED

In Pounds per Day

	110 M. G. D.			1930	7½%			1945	15%			1960
	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month
Wet material	31,680	35,640	27,830	51,370	34,056	38,313	29,917	55,223	36,432	40,986	32,004	59,075
Centrifuged mat.	23,870	26,730	20,900	38,830	25,660	28,735	22,467	41,742	27,450	30,739	24,035	44,654
Water to be evaporated	7,810	8,910	6,930	12,540	8,396	9,578	7,450	13,480	8,982	10,246	7,969	14,421
Ash	7,700	8,470	6,930	13,530	8,277	9,105	7,450	14,545	8,855	9,740	7,969	15,559
Volatile matter	6,600	7,370	5,940	9,900	7,095	7,923	6,385	10,642	7,590	8,475	6,831	11,385

TOTAL AMOUNT OF MATERIAL TO BE INCINERATED

In Pounds per Day

	110 M. G. D.			1930	153.75 M. G. D.			1945	196.25 M. G. D.			1960
	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month	Av.	Max. 6 Mo.	Min. 6 Mo.	Max. Month
Wet material	131,560	159,170	105,930	182,380	173,661	205,794	139,079	238,339	214,627	261,375	171,341	292,809
Centrifuged mat.	60,830	72,600	49,830	86,130	77,319	92,848	62,903	107,854	93,389	112,575	75,648	129,041
Water to be evaporated	36,190	44,200	28,930	49,060	48,063	58,932	38,200	64,525	59,614	73,242	47,219	79,576
Ash	8,910	10,120	7,755	15,554	9,968	11,411	8,603	17,374	11,014	12,684	9,441	19,170
Volatile matter	13,970	16,280	12,045	18,656	17,395	20,375	14,917	22,879	20,740	24,372	17,724	27,008

York, was selected for use. Large-scale tests conducted in a nearby incinerator of the garbage type demonstrated rather conclusively the futility of expecting that any unit of the iron-grate type would give satisfactory performance, because of the high silica content of the admixture of screenings and grit, due largely to the presence of the grit which, when subjected to the temperature necessary, fused at such a rate and in such quantity as to render the grate entirely useless. This fusing upon the grate would not only shut off the air supply almost completely, but would also destroy the grate.

In the units selected, two at 20 tons each per 24 hrs., grates are entirely absent, and in their place refractory materials are to be used. It is reasonable to expect that with such materials fusing will to a large extent be eliminated, also the possibility of excluding air necessary for combustion, this type of unit not depending to any degree upon the air being drawn through any type of grate. The design offered by the Morse Boulger Company embodied the following principal features:

1. The sloped and drained charging floor is unobstructed, with three charging holes per unit, this arrangement making the introduction of the material relatively easy. Furthermore, charging in three places means that the material will be somewhat spread out before entering the incinerator.

2. There are approximately 105 sq. ft. of refractory surface area per ton of capacity. It will be recalled that the water in the material is enclosed in the cell structure; therefore, by providing this large surface area, it is possible at one and the same time to spread out the material and to break down the greatest number of these cells, as well as to gain a large evaporating and heat absorbing surface.

3. Many stoking doors are provided for ease of accessibility to all parts of the unit.

4. Inasmuch as the elimination of odors from the burning process is desirable, a long path for the travel of the gases is provided, the units are long and narrow, and the refractory burning surfaces are relatively near the arches above them, which should result in forcing the refractory heat downward and into the material.

Other points worthy of comment and which were considered of material importance by the Commission's engineers having to do with this design are:

1. The retention of the volatiles in contact with refractory materials for a comparatively long time.

2. The furnishing of an ample supply of air for combustion, not directly to the volatiles, but rather in such a way that the air is hot when it hits the burning gas, this fact being important where smoke, soot and odor are to be eliminated, as usually is the case.

3. The fact that the destructor is long and narrow, the scrubbing action of the flame entering from the end opposite the flue is exerted at every point within the incinerator, except in the last settling chamber, where the gases are expanded.

Theoretical Heat Balance

There is present in one unit or ton of the centrifuged screenings and grit about 65 per cent of water, or 1300 pounds. The heat required to raise this quantity of water to steam at 1250° Fahrenheit is equivalent to about 2,127,000 B. t. u. The heat required to raise the ash, which is 14 per cent of the centrifuged volume, representing 280 lb. of ash per ton, to 1250° Fahrenheit is 61,000 B. t. u., and that required to raise the 21 per cent or 420 lb. of combustible matter combined with about 23 lb. of air to be supplied per pound of combustible, is 2,930,000 B. t. u. The heat calculated to be lost through radiation is about 300,000 B. t. u. By addition the total heat required is theoretically established at 5,418,000 B. t. u. per ton.

From analyses made in our laboratories, it has been estimated that 1 lb. of combustible centrifuged material will contain about 9000 B. t. u., which, when multiplied by the 420 lb. of combustible per ton, indicates that about 3,780,000 B. t. u. will be supplied by the material to be incinerated, leaving 1,638,000 B. t. u. to be supplied directly by the consumption of fuel, which in our case is to be fuel oil.

Upon the assumption that 1 gal. of fuel oil containing 150,000 B. t. u. will deliver about 110,000 B. t. u. for useful work in the process of incineration, it may readily be calculated that about 15 gal. of oil will be required to incinerate 1 ton of screenings, this calculation taking into account the difference between the total heat per gallon of oil and the total heat available for work per gallon of oil as representing the heat carried out in the gases at 1250° Fahrenheit.

It is estimated that about 600 gallons of oil will be required per 24-hour day to incinerate completely 40 tons of centrifuged screenings and grit, this quantity of centrifuged material representing that contained in the anticipated sewage flow as of the year 1940, namely 139 m. g. d.

With fuel oil varying in cost in the vicinity of 5¢ per gallon, the total cost, based upon incineration at the rate of 40 tons per day, may be expected to vary somewhere between 75¢ and $1.00 per ton. Interest, depreciation, maintenance and labor charges may be expected to add another dollar per ton, bringing the total cost chargeable to incineration to a point somewhere between $1.75 and $2.00 per ton. These figures, however, are to be viewed only in the light of and for the purpose for which they are stated herein, namely, that of affording an approximate idea only at this time relative to possible operating costs.

The incinerator manufacturer guaranteed the following performance of the equipment offered and purchased:

"These destructors are guaranteed to be capable of destroying to a clean ash or clinker not less than 20 tons in 24 hours of the sewage screenings as specified.

"The destructors in full or partial operation shall not cause nuisance due to the escape of obnoxious odors or gases.

"All sewage screenings and similar combustible refuse charged into the destructors shall be dried and burned to a mineral ash containing not more than 1 per cent organic matter.

"The destructors are guaranteed against defect in material and workmanship for a period of one year.

"We hereby guarantee that there shall be no smoke during the operation escaping from the chimney of a degree of density greater than that determined by Chart No. 1 of Ringleman's Smoke Scale.

"We hereby agree and guarantee that the full requirements to dispose of the hourly capacity of each unit shall not exceed 12½ gallons of oil having an average fuel value of approximately 150,000 B. t. u. per gallon.

"Although not required by your specifications, we hereby guarantee that under normal and proper operation and operating conditions, no nuisance shall be derived from the presence of fly ash or dust passing into the atmosphere from the chimney."

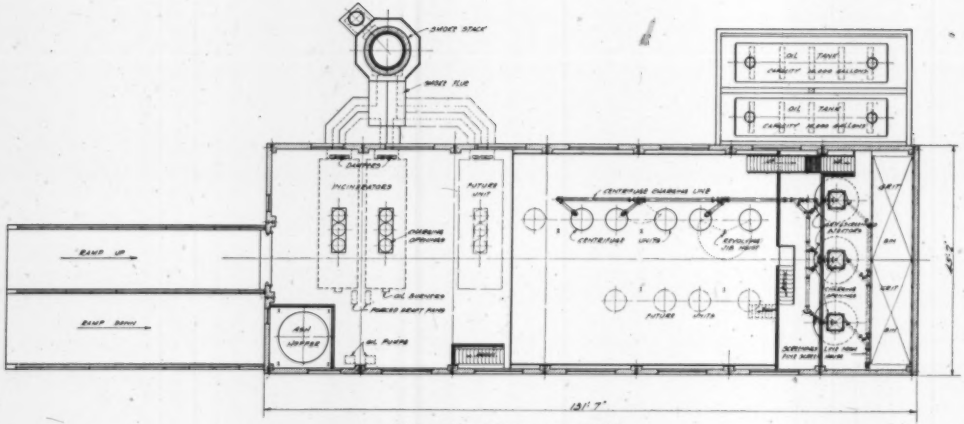
Description of Dehydration and Incinerator Plant

Figures 1 and 2 show diagrammatically the arrangement and relative position of the various equipment in the layout as a whole, and also the basic data pertaining to the quantity and moisture content of the screenings and grit, both before and following dehydration by centrifuging.

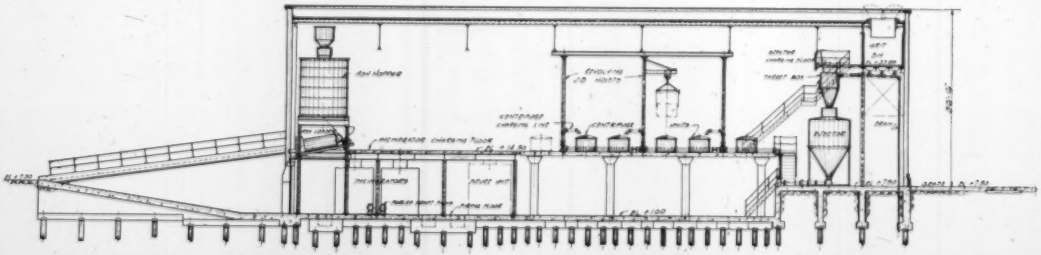
Briefly, the operation of this plant is expected to be about as follows:

Fine screenings are to be discharged from their present source of origin by the use of existing pneumatic ejectors through underground pipe some 500 ft. in length, and into one or the other of three 500-cu. ft. capacity pneumatic ejectors located within and at one end of the incinerator building. These ejectors were manufactured by Pneumatic Ejectors Inc., Newark, N. J. The grit is to be removed from the grit chambers, as at present, and hauled either in railroad flat cars, as at present, or by truck, and thereafter deposited by locomotive crane clam-shell bucket into draining bins located in the incinerator building at an elevation somewhat higher than that of the top of the ejectors, from which point it may be placed by manual labor into the top of one or the other of the 500-cu. ft. ejectors and there mixed with the fine screenings as they are received intermittently.

After an ejector has been filled, the flap gate at the top will be closed,



Floor Plan of Incinerator Building



Longitudinal Section of Incinerator Building

after which its contents will be forced through a suitable pipe line by the application of sufficient air pressure within the ejector, to each of any one of the five specially designed centrifugal machines, as manufactured by the Tolhurst Company of Troy, N. Y. These machines are located on the centrifuge floor, which is on the same level as the charging floor above the incinerators.

The baskets of each of the centrifugal machines, which revolve at a speed of about 500 r. p. m., will hold 12 cu. ft. of wet screenings and grit. After the centrifuging cycle has been completed, the hinged cover of the unit is raised, and the basket is removed from the machine by means of small electric jib cranes. The basket is swung outward, then inverted, its contents falling into a hand-propelled buggy of suitable size to hold two such charges. The contents of the buggies are deposited on the floor above the incinerator near the charging holes, from which place they are fed by hand into the incinerators.

The fuel oil tanks are located in a suitable pit, outside of the building, in which provisions are made for supplying heat during colder months of the year. Small oil pumps are to be used for pumping the oil from the tanks to the Anthony Nebulite burners, with which each incinerator unit is to be equipped.

Ash removal is to be effected by the use of a Nuveyor ash conveyor system as manufactured by the United Conveyor Corp. of Chicago. This type of equipment was selected, among other reasons, because of its apparent advantages in coping with a dust nuisance which may possibly occur when ash is removed from the incinerators. The collected ash is to be deposited in an overhead cast-iron ash bin from which point it will be discharged through a washer and into trucks and hauled away for filling purposes.

The coarse screenings, which at the present time are centrifuged in the coarse screen building located at some little distance from the site of the incinerator building, will continue to be centrifuged in this location as at present, and will be hauled by truck at intervals of possibly two or three times a week, as the occasion requires, to the incinerator plant.

The two incinerators are to be served by a stack 100 ft. in height and 5 ft. in diameter, sufficient oversize having been allowed to accommodate a possible 40- to 50-ton future unit. The contract for erecting the stack was awarded to the Alphons Custodis Chimney Co., of Chicago.

This plant when complete, which will be late in the summer of 1932, will have cost about $121,071, all of the contracts at the present time having been awarded.

The work of furnishing the necessary equipment as previously noted was awarded to the several manufacturers mentioned, the contract for the

housing structure complete having been awarded to the Stark Construction Co., a local contractor.

The total expenditure involved in each and all of the contracts is as follows:

1.	Building structure complete, including wood pile foundation, two 10,000 gal. fuel oil tanks, service tunnel and 24-in. terra cotta and concrete connecting sewer	$ 58,400
2.	Morse Boulger Destructor Co. furnishing and erecting incinerators	20,583
3.	Pneumatic Ejectors Co., furnishing three 500-cu. ft. pneumatic ejectors, with appurtenances and piping	9,505
4.	Tolhurst Machine Works, Inc., furnishing five 48-in. centrifugal machines, motor drives and automatic time switches	14,175
5.	Bayley Blower Co., 2 motor-driven fans for air supply to Anthony Oil Burners	536
6.	United Conveyor Corp. ash conveyors, ash bin and washer, furnished and erected	8,187
7.	Harnishfeger Corp. electric jib cranes	1,635
8.	Alphons Custodis Co., stack 5 ft. dia. 100 ft. in height, erected	5,050
	Total contract cost	$118,071
	Probable additional cost for erecting items 3, 4, 5, 7 and extending water, heating, electric, screenings and compressed air lines from nearest available points to incinerator building	3,000
	Probable total cost	$121,071

Conclusion

In closing this paper, it appears quite appropriate to direct attention to the existing broader fields in the art of sewage treatment to which the incineration of sewage wastes may ultimately be adapted, namely, the dehydration and incineration of waste sludge, which, from the standpoint of the relative quantity produced in a plant of given size, is many times greater than the quantity of screenings produced.

Within the past year or two, considerable impetus has been acquired relative to the analysis of the economic possibilities involved in this problem. Most notable and extensive perhaps along this line has been the experimental and development work of the engineers of the Sanitary District of Chicago.

The engineers of the Sewerage Commission of Milwaukee during the past year have studied this problem to some extent, having in mind the immediately necessary construction of a substantial addition to the present sewage treatment works, in which is involved the problem of disposing of and additional quantity of sewage sludge in the most economical and practical manner.

It may be anticipated that the continued study of this problem during the next two or three years will result in a marked degree of development.

The Economic Preparation and Sale of Digested Sludge as Commercial Fertilizer*

BY M. W. TATLOCK

Supt. Sewage Treatment Works, Dayton, Ohio

The disposal of sludge from any sewage treatment plant constitutes one of the chief problems of plant operation. Whether or not it can be done profitably will depend primarily on the quality and quantity of the sludge itself and upon the equipment provided in the plant design for handling it.

The Dayton Treatment Works is an Imhoff sedimentation type plant designed for a population of 262,000. The sludge compartments provide for six months' storage with a capacity of 0.0082 cu. ft. per capita per day. The sludge is removed by gravity flow to the ejectors which discharge onto the glass-covered sludge beds. There are eleven glass-overs, each 59 ft. 10 in. by 162 ft. 6 in. inside; a net drying area of 9600 sq. ft. per house. The total area, 105,600 sq. ft., is based on an assumed requirement of 0.4 sq. ft. per capita. The drainage provided is 18 in. of graded gravel and sand laid over four rows of 6 in. open joint vitrified tile in each house. The drainage from these lines is discharged into the plant effluent conduit.

The quality and quantity of sludge handled in 1931 are shown in Tables I and II. All operating records are kept on a thirteen-month calendar, each period being four complete weeks.

It is of interest to note in Table I that there was a somewhat progressive change in the per cent solids and per cent volatile matter in the sludge through the year, and that these variations, particularly the per cent volatile matter, seem to follow closely the temperature variations.

Wet sludge specific gravities are determined by comparing weights of water and sludge in a ground glass stoppered bottle. The dry sludge figure is obtained by weighing a definite volume of sludge and comparing its weight with that of an equal volume of water. The pH values are obtained on a sample filtered through cotton to remove enough of the suspended solids to permit a colorimetric reading. A sample filtered through filter paper will give a higher reading.

If there are economies in the preparation of digested sludge as a fertilizer, they must begin in the sludge beds. We consider that any sludge showing 20 per cent solids on the beds can be removed, if necessary, but such removal is quite expensive from the standpoint of labor required and the quantity of sand which adheres to the wet mass. Sludge showing lower than 65 per cent moisture handles best and most economically.

The effect of handling wet sludge is shown by a comparison of 1931 and

* *Presented before the Fifth Annual Meeting of the Central States Sewage Works Association, Rockford, Ill., May 14, 1932.*

TABLE I

WET SLUDGE, DAYTON, OHIO, 1931

Period*	1	2	3	4	5	6	7	8	9	10	11	12	13
Th. Cu. Ft. to Beds	128.4	127.2	66.4	112.0	69.6	81.6	82.4	109.4	133.9	109.1	113.5	134.3	120.7
% Solids	3.96	3.84	3.90	4.89	4.29	4.60	5.30	6.25	4.99	5.20	5.19	4.92	5.11
Specific Gr.	1.015	1.005	1.001	1.006	1.015	1.003	1.011	1.014	1.010	1.007	1.010	1.006	1.015
pH	6.7	6.8	6.8	6.8	6.6	6.6	6.8	6.7	6.8	6.9	6.7	6.7	6.7
Th. Lb. Solids	386.3	382.5	357.4	452.4	321.0	318.1	368.4	443.5	420.2	398.0	371.3	399.8	412.3
% Volatile Solids	63	63	63	63	60	60	59	55	55	52	52	52	54
% Ether Sol.	13	13	14	14	12	12	13	11	10	11	11	11	10
% Total N	3.75	3.79	3.56	3.12	4.11	3.74	3.02	2.86	3.14	2.95	2.93	3.11	3.13
Avg. Daily Temp.	2.2	4.0	4.8	11.2	13.6	21.9	27.2	25.1	22.0	19.9	11.4	12.0	8.2

Summary for Year:

Total Cu. Ft. to Beds	1,388,500
Avg. % Solids	4.8
Avg. Specific Gravity	1.009
Avg. pH	6.7
Total Thousand Lb. Solids	5,031.2
Avg. % Volatile Solids	58
Avg. % Ether Soluble	12
Avg. % Total Nitrogen	3.40
Avg. Depth Dosage, In.	9
Lb. Solids per Sq. Ft.	52.5*

The figure reported for each period is either the total for that period or an average of all samples for that period. In the summary for the year, averages given are mathematical, not weighted averages.

* Only ten houses used for drying, one was used all year for storage of dried material.

TABLE II

DRY SLUDGE, DAYTON, OHIO, 1931

Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Avg. Days on Bed	16	13	17	13	14	17	15	16	16	14	14	15	19
Houses Cleaned	14	19	12	18	11	14	14	15	13	15	16	17	13
Cu. Ft. Removed	45,200	43,200	28,400	30,200	19,000	20,000	14,400	16,400	12,400	15,400	16,600	18,640	17,560
% Solids	20	22	23	31	38	46	55	55	49	45	35	32	24
Specific Gr.	0.760	0.760	0.760	0.760	0.727	0.704	0.625	0.693	0.686	0.739	0.760	0.741	0.800
Th. Lb. Solids	430.8	453.5	295.8	395.2	296.0	376.1	288.0	352.6	253.0	309.7	286.0	273.6	208.2
% Volatile Solids	62	60	56	59	57	56	55	54	51	50	49	50	54
% Ether Sol.	14	10	12	10	10	8	11	10	7	8	9	10	9
% Total N	3.34	3.54	3.25	3.12	3.07	3.44	3.50	2.98	2.91	2.76	2.78	2.68	3.06

Summary for Year:

Avg. Days on Beds	15
Total Cu. Ft. Removed	297,400
Avg. % Solids	37
Avg. Specific Gravity	732
Total Thousand Lb. Solids	4,217.5
Avg. % Volatile Solids	55
Avg. % Ether Soluble	9
Avg. % Total Nitrogen	3.11
Avg. Depth Dried, In.	1.6
Total Cost of Removal	$4,110.30
Cost of Removal per Ton dry solids	$1.95

The figure reported for each period is either the total for that period or an average of all samples for that period. In the summary for the year, averages given are mathematical, not weighted averages.

1932 resanding requirements. During 1930, it was necessary to remove sludge just as soon as possible; this resulted in the required replacement of 5 in. of sand. During 1931, it was possible for the sludge to dry more thoroughly and only 3 in. of sand had to be replaced. The cost of this work each year was $1.07 per yard, which covers all labor and material costs. All sludge is forked off the sand into industrial cars and hauled to the sludge dump, about 800 ft., by a gasoline locomotive. During the first year of operation a locomotive operator and brakeman were hired and six men were used to load the cars. One day or 64 man-hours were required to clean each house. A new foreman was hired to operate the locomotive; 14-tined coal forks were substituted for the 6-tined manure forks previously used and the time required for cleaning each house was cut to approximately 24 man-hours, a savings of 63 per cent over the original cost.

In the latter part of 1930 some sludge was left on the beds until it contained only 10 to 15 per cent moisture and this dry sludge was ground through the cylinder of a wheat threshing machine. This was not very fine so it was screened before it was put up in bags for sale. No particular sales effort was made, but talk among friends and before luncheon clubs created considerable demand. Its use on the lawns about the plant and on the fairways of the adjacent golf course were so demonstrative of its worth that sales began to increase rapidly. The same procedure was followed in the spring of 1931. The material available at that time was sludge which had been stored the summer before in one of the glass-overs.

In June, 1931, a hammer mill was purchased, equipped with a cyclone blower and sacker, after trial on a grain mill of similar type showed it would grind the sludge. No great sales effort was made, but a few contacts through interested farmers resulted in the sale of about 60 tons last fall. The house previously used for storage was completely filled with dried material from the other houses. No close check was kept of the contents, but it was estimated to contain 400 tons. The disappointment came when it was found to contain only 225 tons and the demand for sludge exceeded our ability to furnish it as fast as demanded by our sales organization.

Sales are made either at the plant for cash or to agents who have some definite territory assigned to them. There are two working Dayton, one who has greater Cincinnati and Hamilton County and seven working in the counties surrounding Dayton. The retail price is $1.00 per 100 lb. unless the purchase is 1000 lb. or more, then the rate is $15.00 per ton. The wholesale price to agents is $8.50 per ton, subject to 5% discount in 30 days.

When it was discovered that the demand would be greater than the amount of dried stored material, hurried plans were made to get more

dried material. An old asphalt mill, junked by the Street Department, was set up as a drier and a pipe line laid to supply Imhoff tank gas for fuel. This mill was only 20 ft. long and although it was rotated slowly enough to require about 40 min. for the material to pass through, it did not prove very successful. Some more junk material was utilized. A hot plate 10 ft. × 12 ft. was built, using old fire brick and discarded cast-iron manhole plates for the top. The wet sludge was heated on this, using Imhoff gas for fuel, before it was fed into the drier. Another difficulty presented itself. The larger lumps of semi-dry sludge were too large to get hot through, so the old separator cylinder was pressed into service as a pulverizer. The capacity of this junk outfit is now 1 to $1^1/_2$ tons per hour, taking material at 40–45 per cent moisture and turning it out at 8–10 per cent.

Profits realized from any business must take into consideration the capital investment, operation costs and the income from sales. These items are summarized in Table III.

TABLE III

Capital Investment	$1069.78
Operation Cost	3356.18
Sales to May 10, 1932	4793.35

This investment figure includes the cost of the mill, motors, elevators, gas and electric feed lines and labor involved in their installation. The operation cost includes all repairs for the mill, bags and ties, state sales license fee, the cost of sludge purchased at Indianapolis to supplement our supply, and all labor involved after the sludge is loaded in the cars ready to transport to the mill.

If only operation costs and sales are considered Table IV gives their comparison.

TABLE IV

Total Sales to May 10, 1932	475 tons	$4793.35
Total Cost of Production:		
Maintenance and Supplies	$1789.50	
Labor	1566.68	
Total	$3356.18	3356.18
Net Profit		1437.17
		$4793.35

The cost of removing sludge from the beds has been $471.60. If this is deducted from the net profit shown above, the preparation and sale of sludge has shown a profit of $967.57 over all charges for sludge handling in 1932 on a capital investment of $1069.78 for equipment to do the work.

At this writing we have orders for approximately 200 more tons, the

most of which will be delivered to tobacco growers. These sales were the result of the sale of one crop which was fertilized last year with sludge and when it was sold it had all the qualities looked for in a high grade tobacco and brought a premium price.

What the future has in store as to demand and sales is a question at this time. The salesmen are quite enthusiastic about the prospects, but the results obtained on this year's crops will likely carry more weight than their enthusiasm.

As a result of the writer's experiences in this enterprise, he is inclined to believe that sludge can be successfully marketed, but it cannot be done without working at the job.

The New-Activated Sludge Plant at Phoenix

BY DARIO TRAVAINI

Plant Superintendent, Phoenix, Arizona

Until recent years sewage treatment has been a matter of no concern to the citizens of Phoenix. Their trust has been placed in two septic tanks of ancient design, promised panaceas for all waste disposal problems. The population grew with the rapidity customary in prosperous irrigated sections; the water supply was increased from time to time without a thought that waste water was also increasing in volume. One septic tank collapsed; the other began to disintegrate, discouraged by the excessive burden. The sewage flowed away from the contributors in the "ditch," and, after a sturdy effort to irrigate fields, was discharged into a more or less dry channel of the Salt River. The bubbling creek thus formed was far enough from the city limits not to cause lifting of municipal noses, but the country folk and U. S. Indian Service became all too familiar with venturesome hydrogen sulphide gas.

Finally a survey of the sanitary condition of the Salt River was made by the State Board of Health with the coöperation of the U. S. Public Health Service. The results of this investigation helped to convince the municipal authorities that more adequate sewage disposal was necessary before further enlarging the domestic water supply, and that the plant must be designed to minimize noxious odors and furnish relief to the abused senses of the farmers living west of Phoenix.

It was not feasible to make any experimental plant studies, but W. J. Jamieson, City Engineer, and C. C. Kennedy, Consulting Associate Engineer, concluded that a plant using the activated-sludge type of treatment, with covered digestion tanks, was best suited to control odors. Chlorination of the final effluent was added to prevent further pollution of the river and to make the water suitable for irrigation.

Trunk Lines.—A 48-inch line serves the south and east sections of the city; a 36-inch line the west and north sections. These join into a 54-inch outfall a quarter of a mile above the plant. The trunk lines are reinforced spun concrete pipe, tiled with vitrified clay from below the minimum flow line to the crown. The outfall enters a diversion chamber, hexagonal in plan, which connects with the screen house and also provides a means to bypass the flow around the plant. (Fig. 1)

Screen House.—The cross section of the screen channel is 5 by 5 feet, provision being made for another channel for future use. The bar screens are set at an angle of 30° from vertical, with 2- by 1/4-inch galvanized-steel bars spaced with 1-inch clearance. The screen is automatically mechanically cleaned by float control. The screenings are collected in galvanized iron hoppers of 8 3/4-cubic feet capacity.

The screened sewage is measured in a Venturi flume with a recording device having a connection to the power house.

Preliminary Clarifier.—The clarifier tank is 85 feet square, $12^1/_2$ feet deep to the intersection of the vertical wall and the hopper. The flow line is $2^1/_2$ feet from the top of the wall. The tank capacity of approximately 530,000 gallons provides a retention period of one hour and a settling rate of 1660 gallons per 24 hours per square foot of surface area when the flow is at the designated capacity of 12 m. g. d. At present the flow is 7.2 m. g. d.

FIG. 1.—Phoenix Treatment Works, Screen House, Preliminary Clarifier, Aerators and Chlorine Unloading Facilities at the Power House.

allowing a retention period of $1^3/_4$ hours and a settling rate of 1000 gallons per square foot.

Aerators.—The five aerators are 330 feet long, 27 feet wide, and 14 feet deep from the flow line to the bottom of the tank. The base of each aerator is divided into two compartments with rounded cross section, a single row of porous plates for diffused air being placed on the dividing wall 4 feet above the lowest level of the tank floor. Each aerator is provided with 260 plates. The air is supplied by four General Electric compressors, each capable of supplying 1000 cubic feet of air per minute. Only two blowers are being used now. It is estimated that 0.2 to 0.3 cubic feet of air per gallon of sewage will be needed.

Agitation is supplied by mechanically operated paddles; each set throughout the length of the tank being offset $13^1/_2°$ and revolving against the air stream at approximately 4 r. p. m. (Fig. 2) Power to drive the paddles is supplied by twelve 10-horsepower United States motors with

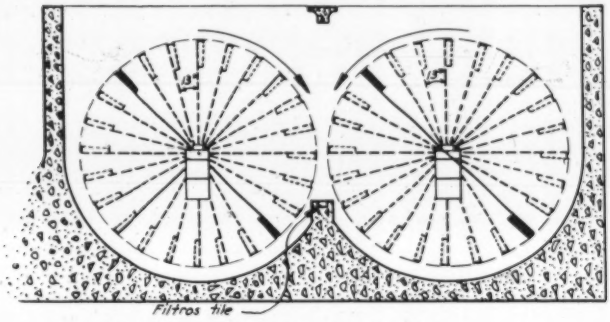


FIG. 2.—Cross Section of Aeration Tanks.

gear reductions. It is not planned to house these motors, which are placed on a concrete slab over the aeration tanks. (Fig. 3)

Sewage enters the aerators through submerged rectangular sluice gates connected with the conduit carrying the effluent from the preliminary clarifier. The reaerated sludge enters the aeration tanks over weirs from the reaerated sludge channel, which is placed directly over the conduit for the clarifier effluent. With the present flow three aeration tanks are in service giving a retention period of $6^1/_2$ hours.

Sludge is returned to the reaeration tank, which is of the same design and dimensions as the aerators, by three airlift pumps having a maximum

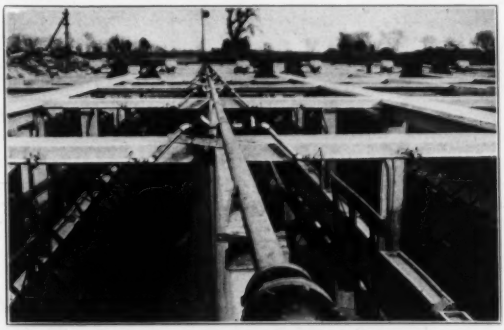


FIG. 3.—Aeration Tanks, Showing Paddle Wheels and Diffuser Plate Boxes.

capacity of approximately 3 m. g. d. An 8-inch Price centrifugal pump has also been installed. The piping is arranged so that the sludge from the secondary clarifier can be returned either to the reaerator or to the aerators.

Secondary Clarifier.—The secondary clarifier is 140 feet square, 11 1/2 feet deep to the intersection of the vertical wall and hopper, with the flow line 2 1/2 feet below the top of the wall. The tank capacity is 1,300,000 gallons, furnishing a retention period of 2.1 hours when the flow is 12 m. g. d. plus 25 per cent of returned sludge. At this load the settling rate will be 780 gallons of mixed liquid per square foot of tank area. The retention period at the present time is approximately 4 1/2 hours.

The effluent flows over notched weirs into a metal launder, supported by brackets at varying distances from the tank wall. The total weir length provided is approximately 350 feet.

Contact Channel.—The effluent from the secondary clarifier discharges into a chlorine contact channel, which is a ditch lined with gunite 825 feet long, 5 feet wide at the bottom, and 8 feet deep, the sides being on a slope of 1 to 3/4. A concrete structure at the discharge end contains 4 overflow weirs and a sluice gate to drain the channel. The retention period is varied by changing the height of the weirs. The channel empties into a short pipe line leading to a ditch 1500 feet long, through which the plant effluent flows to the main channel of the Salt River. When the arrangements for chlorination have been completed, it is hoped to sell this water for irrigation.

Sludge Thickener.—In order to increase the percentage of solids in the sludge pumped to the digesters, and also to decrease the amount of overflow from the digester, a tank 35 feet in diameter and 10 feet deep, with the flow line 1 foot below the surface, has been equipped with special Dorr mechanism. In addition to the conventional scrapers of the clarifiers, a picket fence arrangement of pipes is attached to one radius of the two scrapers, extending slightly beyond the center of the tank.

The retention period will vary widely, depending upon the amount of excess activated sludge wasted and rate of pumping from the preliminary clarifier. The overflow goes to this clarifier.

Sludge Piping.—The sludge piping is so arranged that the solids from the preliminary clarifier may be pumped either into the thickener or directly to the digesters. The activated sludge that is wasted may be pumped to the thickener or returned to the preliminary clarifier for re-settling. Three duplex Dorrco-Barnes variable stroke plunger pumps, each with a capacity of 150 g. p. m. for a maximum total head of 25 feet, are provided to pump sludge from the preliminary clarifier or the thickener to the digesters.

Digesters.—The two digesters are 60 feet in diameter, 23 feet deep and each has an approximate capacity of 500,000 gallons. Three-inch wrought iron pipe coils convey hot water to maintain favorable digestion

temperatures at all times. Mechanical scrapers are provided to stir the sludge in the bottom of the tank and to break up the scum forming on the top. The gases generated by digestion are collected by two gas domes on each digester.

Gas Holder.—A gas holder with 950 cubic feet capacity will take care of excess gas at such times as the gas production may be greater than the consumption and also will aid in maintaining a uniform pressure.

Sludge Drying Beds.—Six drying beds, 125 by 40 feet in place with tile underdrains, are equipped with a belt conveyor which can be moved from one bed to another. Dried sludge shovelled on to the conveyor will be mechanically loaded into trucks.

The mechanical equipment used in the several units of the plant has been furnished by the Dorr Company. The controls for operating the equipment are located in the power house, as are the compressors, sludge pumps and boiler. The laboratory and office are in the administration building. The primary units of the plant were placed in operation March 15, 1932; the secondary units went into service April 10th. The present crew consists of three operators and three helpers. It is difficult to estimate the amount of labor that will be necessary for satisfactory maintenance until routine operation has been established.

It is too early to give any estimate of the performance of the plant. Mechanical equipment is being adjusted and operating details are being worked out; until activated sludge is built up in the aeration tanks, it will be impossible to judge the character of the final plant effluent. It is obvious, however, to even the casual observer that liquid flowing through the outlet channel, if not of the clear sparkling quality of mountain brooks, at least lacks the bubbling activities of the old "ditch."

New Canaan, Connecticut, Sewage Treatment Works

BY JOHN G. ALBERTSON

Associate Engineer, Thomas F. Bowe, Consulting Engineer, 110 William St., New York, N. Y.

The Borough of New Canaan is situated in the southerly portion of Fairfield County, Connecticut, and is well known as an attractive summer resort. Its sanitary problem is typical of many Connecticut municipalities. The topography and geology are such as to be conducive of fairly rapid rainfall run-off thus leaving a drainage stream of meager proportions during time of dry weather. This predicament was made more acute by the use of the headwaters of Five Mile River for water supply and the development of residences along the lower reaches of the stream.

Complete treatment was intended by construction in 1907 of a septic tank followed by sand filtration beds. Increased flows, attributable partly to leaky joints and some abuse of the sewer system, necessitated enlargements in sand filter area in 1912 and subsequently a lagoon or flood basin was installed to give settling treatment and chlorination to excess flows. The year 1930 found the sand filters flooded due to reduced ability to serve even normal rates of flow, the lagoon filled with septic sludge and liquid, the open settling tanks with deep layers of odorous scum, and the effluent of poor quality.

The enlargements completed in December, 1931, include a mechanical activation unit designed to give a high degree of clarification in order that the prevailing and near future flows might be applied upon the original sand filter area. Other improvements include plural alternating siphons to apply the clarified effluent to the sand, provision of separate sludge digestion and construction of a glass-covered drying bed.

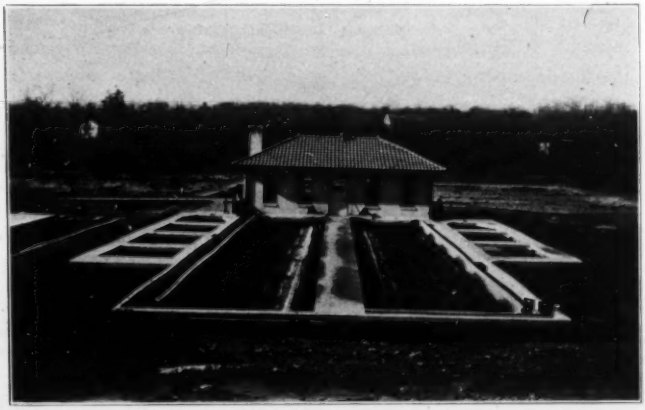
The new plant is designed to treat 0.5 m. g. d. of domestic sewage. The borough had a population of 2372 in 1930, of which approximately 2000 are connected to the sewer system. The average daily flow during the winter season has been between 250,000 and 300,000 with peak hourly rate of 350,000 to 400,000 gallons per day. The system is subject to a high rate of infiltration during stormy weather, for which reason the plant is designed to bypass rates of flow in excess of 750,000 gallons per day to the lagoon and further arranged to bypass part of the 750,000 gallon rate, after sedimentation, to the dosing tank and then to the filter beds.

Control Building.—The control building is 17 by 33 ft. in plan. It is of the Spanish type and houses the following items:

1. All motors driving the mechanical units
2. Flow-recording device
3. Grit and screen mechanism

4. Return sludge-diversion box with adjustable V-notch weir
5. Completely equipped laboratory
6. Lavatory
7. Switchboards
8. Chlorinator
9. Steam heating system
10. Three centrifugal sludge pumps, two for return sludge and one for septic sludge.

Grit and Screen Chamber.—Sewage is directed to the grit and screen chamber after being delivered to the plant through a 16-in. cast-iron



New Canaan Sewage Treatment Works. Straight Line Aerator in Foreground, Settling Tanks at Sides, Control Building in Center.

inverted siphon. The grit sump, triangular in longitudinal cross section, is designed to give an average velocity of one ft. per sec. for a period of 45 seconds. The bottom velocity may be increased during lower flows by an adjustable baffle set across the chamber.

The face of the bar screen and the rear slope of the grit sump are in the same plane, both being on a 45° inclination with the horizontal. The screen bars are 1/4 in. by 2 in., spaced with 1 in. clear openings. A combined motor-operated mechanism, consisting of perforated bucket with rake attachment mounted on endless chains, is arranged to travel downward along the screen and thence through the grit sump, removing the accumulated matter and elevating it to an inclined chute. The method of

cleaning the bars from the downstream side toward the flow precludes the possibility of jamming obstructions into the openings. The slow movement of the buckets through the sewage tends to wash the grit and screenings free from organic matter, while each bucket has ample time to drain on its upward flight.

The mechanism operates continuously and may be observed through the glass panels of the metal partition.

The retained material is deposited in perforated metal cans where it is allowed to drain. The volume has been averaging from 2 to 3 cu. ft. per day, with a weight of 57 lb. per cu. ft. This drains to 45 lb. per cu. ft. in 24 hours. During times of storm flows, grit and materials which have been deposited in the inverted siphon are washed into the grit chamber in large quantities. After one storm 12 cu. ft. were removed.

Primary Tank.—The plant has one primary settling tank 10 ft. wide by 10 ft. 3 in. average water depth by 43 ft. long, with a detention period of 1.5 hr, for 0.5 m. g. d. The tank is equipped with a Link-Belt straight-line sludge collector which draws the sludge to a sump at the influent end of the tank. The collector is run 30 minutes in the morning and 30 minutes in the afternoon, before the sludge is pumped. Sludge is pumped to the digestion tanks from 5 to 10 minutes every day at a rate of 250 g. p. m. The sump is equipped with perforated water coils which can be used to break up the sludge if it clings to the sides. To date very little trouble has been experienced with sucking water through the sludge in the sump or sludge clinging to the sides. The sludge has a moisture content between 96 and 99 per cent.

The raw sewage as it reaches the primary tank has an average composition as follows:

Settleable Solids	2.5 to 4.0 cc. in 1000 cc. Imhoff Cone
Suspended Solids	80 to 140 p. p. m.
B. O. D., 5-day	100 to 250 p. p. m.

The tank removes between 90 and 100 per cent of the settleable solids in the sewage, measured by settling a sample of influent and a sample of effluent, taken at the same time, in an Imhoff cone for two hours. Results are the average of samples taken every hour from 8 A.M. to 4 P.M. The removal of suspended solids varies between 45 and 70 per cent. Samples for this test were taken every 30 minutes and analyses were run on three-hour composites. The reduction in B. O. D. varied between 27 and 50 per cent. Analyses were made at the end of the day on a composite of the 30-minute samples. It was found that the addition of activated sludge to the primary tank increased the per cent reduction of suspended solids and B. O. D.

Aeration Tanks.—Returned activated sludge is admixed with settled

sewage in a channel leading from the primary tank. Admixture is caused by a series of steel baffles placed in staggered positions along the path of travel. These were found to be essential to distribute the sludge uniformly between the two tanks.

The aeration tanks are 16 ft. wide by 10 ft. deep by 70 ft. long. They provide a detention period of 6.15 hours for a flow of 0.5 m. g. d. plus 25 per cent returned sludge. These are equipped with Link-Belt straight-line aerators, which cause the mixed liquor to take a spiral flow through the tank. Baffles constructed under the aerators and parallel to the central wall prevent short-circuiting of the spiral flow.

The aerators revolving at a speed of 45.5 r. p. m. cause a surface velocity of 15 ft. per sec. and a bottom velocity of 1.0 ft. per second. Tests with a flow meter showed that there was motion at every point in the cross-section.

The tanks at present are being operated with 10 to 15 per cent settleable solids, the determination being made by allowing 1000 cc. of the mixed liquor to settle in a graduate for 30 minutes. The suspended solids content of the mixed liquor at the effluent end of the aeration tank is 250 to 350 p. p. m. The pH of the tanks averages 7.1.

Final Tank.—The mixed liquor is settled in a rectangular final settling tank 10 ft. wide by 10 ft. 3 in. av. water depth by 52 ft. 2 in. long, giving a detention period of 1.9 hr. for a flow of 0.5 m. g. d. The sludge in this tank is drawn continuously to a sump at the influent end by means of a Link-Belt straight-line sludge collector. The sludge is pumped continuously from this sump, by one of the activated-sludge pumps, to the diversion box in the administration building. From this box the sludge can be returned to the mixing channel or wasted to the primary by means of an adjustable V-notch weir. The effluent trough in the final tank is T-shape in plan, providing 32 lineal feet of effluent weir. It has been determined by experiment that this design of trough materially reduces the amount of floc leaving the tank at high flows.

The effluent at all times has the clear appearance of drinking water, containing only 1 to 8 p. p. m. of suspended solids, a dissolved oxygen content of 5 to 10 p. p. m. and a B. O. D. of 6 to 8 p. p. m.

Dosing Tank—Sand Filters.—The existing dosing tank was equipped with three interlocked siphons, arranged to apply the clarified liquid alternately upon three pairs of beds, the dose being slightly greater than a layer of water two inches deep over their surface.

The original sand filters, six in number, were dosed with a single siphon, which could be arranged by a system of valves to discharge the flow at one end of any combination or all of the filters. In practice, the sewage was applied on a single bed or pair of beds until clogged and then upon the next and following beds until all were ponded. Very little purification was

effected, since the beds had no opportunity of being reoxygenated. As remodeled, the beds are arranged in pairs and fed through a central longitudinal vitrified pipe located below the ground surface and provided with five vertical outlets spaced at equal distances along the axis. This arrangement distributes the liquid uniformly over the sand area.

The filters were equipped with a new system of underdrains laid at a depth of 3 ft. 6 in. below the surface. An inspection of the original drains, which were laid at a greater depth, indicated that fine material had compacted around them. The drains placed in 1906, however, were clean and contained no deposits. Drainage first appears from the lower pipes in some of the filters and later from the new system at the higher level. Analysis of the sand proved that it was rather fine and lacked uniformity of size. However, inasmuch as the sand could be replaced at any time, it was considered advisable to ascertain whether it would be satisfactory for filtering a highly clarified liquid. The continued use of the sand has been justified, as the filters have indicated their ability to treat the present effluent, the liquid being applied at rates of 400,000 gallons per acre per day. The surface of any pair of beds is dry before a second dose is applied.

Digestion Tank.—The original septic tanks, roofed over with a concrete slab and equipped with water coils and means for circulating the sludge, are being utilized as a digestion tank. The two tanks were arranged to operate in series, the sludge entering at one end of a tank and discharging at the same end of the adjoining tank after a path of travel of 128 feet. The second tank functions as a septic-liquor resettling tank and, as such, produces a clear liquid. This is admixed with 40 to 50 times its volume of final tank effluent and passes through the sand. The dilution with an oxygen-saturated liquid plus exposure to a large surface area of sand satisfies its oxygen demand. As the septic liquid represents less than one-quarter of one per cent of the daily flow, it is considered better to treat it in this manner than to return it to the influent sewer, thereby endangering the process.

Sludge Bed.—The sludge-drying bed is of new construction, equipped with glass superstructure and central trackway for removing the dried material. The drainage is arranged to pass to the old lagoon, where it must seep through a set of underdrains and thence to the stream. In this manner it is twice filtered and highly diluted before final discharge.

Pumping Equipment.—All pumps are centrifugal of the Fairbanks Morse, Wood trash design. They are of the vertical type with motors on the upper floor and pumps in the basement. The pump for septic sludge and those for activated sludge are in no way connected, thus precluding the possibility of error in operation. Piping and valves are painted a characteristic color to designate their type.

The pumps utilized for returning activated sludge are driven by variable-

speed motors each of 1.5 horsepower. Horizontals lip-ring motors operate through bevel gears to drive the vertical pump shafts. As the gear housing is filled with grease, these units operate smoothly and quietly and provide means of varying the volume of returned sludge.

Chlorination.—A vacuum solution-feed chlorinator is installed with point of chlorine application one-third of the tank length from the influent end of the secondary settling unit. The hard rubber diffuser is placed just below the surface and in a clear zone where objects three feet from the surface may be easily discerned. The settling tank serves as a contact tank as well, chlorine solution being effected by baffling at the two-thirds point. It is not anticipated that chlorination will be necessary except when the sand filters are being bypassed. As arranged, the chlorine will not be inhibitive to the bacteria in the activated sludge nor will large doses be necessary to produce a chlorine residual in the effluent.

Power.—The power requirements of the plant are as follows:

Screen Mechanism—Continuous, 0.3 Kw.	7.2 Kw.Hr. Daily
Primary Collector—One Hour Daily, 0.3 Kw.	0.3 Kw.Hr. Daily
Activation Tanks—Continuous, 6.2 Kw.	149.0 Kw.Hr. Daily
Secondary Collector—Continuous, 0.3 Kw.	7.2 Kw.Hr. Daily
Return Sludge Pump—Continuous, 0.7 Kw.	16.8 Kw.Hr. Daily
Septic Sludge Pump—1/4 Hour, 0.7 Kw.	0.2 Kw.Hr. Daily
	180.7 Kw.Hr. Daily

This is equivalent to a continuous load of 7.53 Kw. for the 0.5 m. g. d. flow or 15.06 Kw. on a million gallon basis.

Operating Results.—The effluent from the secondary settling tank, in terms of the layman, may be described as clear transparent non-odorous liquid, while the effluent from the sand filters is crystal clear with a fresh odor and of a quality superior to the water in the stream.

Why Should Municipalities Treat Their Sewage—And How Can They Do It?*

BY FRANK BACHMANN

Manager, Sanitary Engineering Division, The Dorr Co., Inc., Chicago

In view of the tremendous impetus which sewage treatment has received within recent years—an impetus, moreover, which has continued unabated during these trying years of industrial and financial depression—it may be worth while to pause a moment in our consideration of the technicalities of sewage treatment and consider the underlying reasons why public works of this character have recently enjoyed an unprecedented boom. This activity is not confined to any one section—it is as prevalent in the East and West as it is in the Central States, and the same may be said of the South and even Canada.

During the past decade, particularly during the last three or four years, this country has become "sewage-treatment conscious" and alert progressive city officials are now giving much thought to why and how their municipalities may face this problem in sanitation fairly and squarely. This paper, based on comments which the author has received from civic leaders in many parts of our country, will attempt to answer these two vital questions.

If the first place, sewage treatment—and by that, simple sewage disposal is not meant—is a definite trend of the times. A progressive strengthening of the regulations regarding stream pollution and of the powers of those entrusted with their enforcement has been accompanied by a greater civic realization that pollution breeds disease and offensive conditions and as such must not be tolerated. The universal treatment of both municipal and industrial wastes will come in time and in many cases the feeling has grown that if "eventually, why now now?"

In the broadest sense the streams belong to the state by right of eminent domain and as such should be regulated and controlled for the greatest benefit of the greatest number of people. The basic rule of the common law has been stated to be that each riparian proprietor has the right to have the stream come down to him with its quality unimpaired and with its quantity undiminished. Due to the necessities of modern, urban civilization, this rule has been modified to allow reasonable use of the stream by the proprietors above him, but just what constitutes "reasonable use" is a question which has been carried into many courts and has resulted in much litigation. The fact that other municipalities may have a legal right to a stream that is used by an upstream city as a depository for sewage is

* *Presented before the Iowa Sewage Treatment Conference, Iowa State College, Ames, Nov. 19, 1931.*

ample reason for installation of a sewage treatment plant where needed. Failure to do so will probably lead to action on the part of the State Board of Health.

A city should, and often does, consider itself responsible not only for its streets, roads, fire, police and educational facilities but also for the general conditions of the health of its people and for the maintenance of the recreational facilities provided by nature. Modern medical science recognizes the interdependability of public health, pure drinking water and the biological condition of the adjoining water courses. The Izaak Walton League and other groups interested in the protection of our natural heritages have shown the extent to which boating, fishing, bathing and the beauty of our American fields and woodlands have been destroyed or at least jeopardized by the unrestricted and unnecessary discharge of fecal matter into our rivers and streams. Substantial new citizens and remunerative new industries will not be attracted to a city which is deficient in the all-important matter of guarding its people against epidemics of typhoid and other epidemics spread by water-borne human wastes.

To those of you who wish a practical, economic reason for building a sewage treatment plant the conditions of today, born of the depression, should strongly appeal. The basic raw materials, iron, steel, copper, cement, sand and stone are now for the first time in a decade or so down to prewar costs. A plant may be built now at bargain prices. The construction of a plant of this type requires large numbers of unskilled laborers. Here, then, is an ideal way to keep your unemployed occupied and to reduce the funds you may have to raise to care properly for your jobless dependents. And finally, municipal bonds may be floated more easily now than two or three years ago when speculative activity in stocks was at its peak. Now is the time to take advantage of low interest rates which may not come back again for some time.

Even to the uninitiated the operation and maintenance of sewage treatment plants present no hazards. The several processes have reached a high state of technical development, the operating technique and control are reliable and satisfactory, and trouble-free service may be anticipated without question if the design has been entrusted to a reliable consultant. Furthermore the properly designed plant emits no disagreeable odors to antagonize adjoining property owners and the architectural treatment of structures and grounds may be made as attractive and sightly as that of other civic buildings. Sewage treatment plants, far from being eye-sores, and repulsive to the senses as they were twenty years ago, now rank in importance and appearance with the best municipal activities and as such reflect credit and distinction on any city adopting them.

And now a word or two on cost. Sewage treatment is not such an expensive operation that any municipality can reasonably oppose its adoption

on the score of cost. Taking the separate sludge-digestion process as the method best adapted to average conditions in small and medium-sized cities, the following table showing costs at ten plants of this type, may be instructive. Populations and flows represent present, not future, conditions, and unit operation costs include power, labor, maintenance and fixed capital charges at 7½% of the construction cost. It will be seen that construction costs range from $2.62 to $21.70 per capita with an average about $7 to $8. Operating costs range from $0.46 to $2.16 per capita year with an average in the neighborhood of $1.00 to $1.25.

UNIT COSTS AT REPRESENTATIVE SEPARATE SLUDGE DIGESTION PLANTS

Plant No.	Population	Per Capita Construction	Cost Operation
1	2,000	$ 9.30	$1.06
2	2,500	5.24	1.66
3	4,000	4.05	0.81
4	5,000	6.80	0.74
5	5,000	21.70*	2.16
6	5,500	4.37	0.54
7	10,000	9.35	0.98
8	43,000	8.61*	1.41
9	53,000	11.67*	1.01
10	200,000	2.62	0.46

* Includes secondary treatment.

A project for the treatment of a city's sewage may be initiated in any one of a number of different ways, but most common probably are those cases where the State Board of Health insists on remedial measures. When this takes place the problem is lifted at once from speculation as to whether or not a plant is to be built, and placed on the concrete basis of how best to go about the job. A few comments on how a municipality can build such a plant may, therefore, be opportune.

First of all, specialized knowledge and experience is required for a detailed study of local conditions, recommendations as to the type of plant required and preliminary estimates of the probable cost. Except in the cases of the large cities, and seldom even there, this knowledge and experience must come from private firms of consulting engineers. The selection of a consultant is the first and most important step. On this judgment the entire project depends. The very best available man should be selected, one whose professional background and performance record reflect the skill and judgment that he can bring to bear on the problem.

Once the consultant has been selected, give him a free hand and the utmost latitude. Too frequently he is seriously hampered in his activities and often the city insists upon alternate bids being taken on all equipment units, with the award decided strictly on a price basis. The time has gone by when the price of engineering equipment is the governing feature.

The farsighted municipality, today, wants the contractors with whom it does business to make a fair profit, and knows that those who are markedly out of line in price will have to skimp on quality, service or both. All these things the reliable consultant knows from years of experience, so give him your support when he wishes to select and specify the best without securing tenders from less reliable, though cheaper sources.

There is no altruism in municipal sanitation which causes a city to treat its wastes to a greater degree than necessary. Treat, therefore, only to the degree required by the regulating authorities, thus conserving public funds for the future. It is generally considered good practice to build for the population requirement 15 to 25 years hence and to provide such a flexible design that additional units may be installed in the future, either to increase the capacity or to provide such higher degree of treatment as subsequently may be required.

The capital funds required for financing the project are generally raised by the flotation of municipal bonds, provided the city's borrowing power is ample. The placement of these bonds with investment banking houses or syndicates is determined by competitive bids.

The interest and amortization payments on these bonds plus the cost of operating the plant come from taxation of property owners. In certain cases the funds are raised by a direct assessment, but this is generally unpopular and should be avoided if possible.

The modern sanitary district with powers not only to operate and build a treatment plant, but also to float bonds for its construction, is a fairly recent development. It originated in the Middle West, particularly in Illinois, and should become generally useful elsewhere when other states enact the necessary enabling legislature. The formation of a sanitary district is extremely attractive when the borrowing power of the city is not sufficient to raise the capital funds in the usual manner. The sanitary district must be in a common drainage area and the capital and operating charges must be paid by a tax levy on the city or cities served.

After the studies of the sewage conditions have been completed, a decision must be reached regarding the process of treatment to be used. This is an important matter and one to be decided by the consultant and by him alone. While all plants differ in such matters as layout, equipment, etc., they still fall naturally into three major process classifications and modifications thereof. Each of these differs from the others in the degree of treatment provided and, accordingly, each has a more or less well defined field of applicability.

Fine Screening and Chlorination.—Fine screening under the most ideal conditions cannot be considered other than the most preliminary of preliminary treatments. It may remove from 10 to 15 per cent of suspended solids, and while it does deal fairly satisfactorily with the coarse

visible solids it has little or no effect on the much greater volume of fine organic matter.

It is being used successfully at a number of coastal cities—Atlantic City, N. J., Los Angeles, Cal., and others—where the mass dilution of the ocean may be used, but where coarse, visible solids must not be cast upon the bathing beaches. Fine screening is not sufficient for inland cities, such as those in Iowa, or even those bordering on or draining into the Great Lakes, as witness the ruling of the Great Lakes Drainage Basin Sanitation Agreement to the effect that "minimum treatment shall be efficient sedimentation."

Sedimentation, Digestion and Chlorination.—Sedimentation and digestion, either in two-story tanks of the Imhoff type or in separate, mechanically cleaned tanks, is generally considered a satisfactory preliminary treatment. It will generally remove 55 to 65 per cent of the suspended solids and reduce the B. O. D. 30 to 35 per cent. Followed by chlorination it finds a wide field of utility among small or medium sized cities where relatively large adjoining streams supply the necessary mass dilution effect. Its use is especially prevalent in the middle western states—Toledo, Ohio, Grand Rapids, Mich., Fond du Lac, Wis., and others.

Sedimentation Followed by Biologic Treatment.—The addition of biologic treatment makes a plant of this type complete and provides what has come to be called "complete treatment." The biologic treatment of the sedimentation tank effluent may be aeration by the activated-sludge process or treatment on sprinkling filters, or, less frequently, contact beds. With this arrangement the removal of suspended solids may be as high as 90 to 95 per cent and the reduction of B. O. D. 85 to 95 per cent.

This type of plant is well adapted to conditions at large or medium sized cities whose adjoining water courses are small or, if large, highly congested. Among the large cities using this system with the activated-sludge option are Chicago, Milwaukee, Fort Worth, Peoria, Springfield, Ill., North Toronto, and others. The trickling filter option is used at Aurora, Ill., Elgin and Decatur, Ill., Baltimore, Md., Madison and Antigo, Wis., and others.

The distribution of the various types of treatment may well be illustrated by the records of the use of the equipment manufactured by the author's company, which favors no particular process, at the slightly more than two hundred cities which use this equipment and contribute a daily total sewage flow of about two and a half billion gallons. Approximately 8 per cent of these cities use fine screening alone, about 55 per cent sedimentation and sludge digestion, with or without biologic filters, 30 per cent the activated-sludge process and the balance miscellaneous methods such as sedimentation or chemical treatment.

Summary and Conclusions

The unprecedented activity which the sanitation field is now enjoying is a trend of the times and the general desire for conditions beyond the reach of the last generation. Municipalities should build sewage treatment plants and should do it now because (1) universal treatment is sure to come in the future, (2) the state will continue to regulate stream pollution upon the principle of the common law and the greatest good for the greatest number, (3) the city should hold itself responsible for the health of its people, (4) material and money are cheap now and unemployment prevails and (5) the modern, odorless, attractive plant is not expensive to build or operate considering the widespread benefits it brings to the city, its residents and its industries.

The key man in any sewage treatment project is the consultant and he should be selected with the utmost care and given a free rein in the design of the plant and particularly the specification of equipment. Once selected, such a consultant will answer authoritatively the question as to how the plant is to be built and operated, for upon his mature judgment will rest the responsibility of treating to the degree required by means of that process which is most applicable to the particular conditions at hand.

The sincere and universal interest in sewage treatment today is not a coincidence but a great step forward, motivated by that subtle, yet powerful force known as public opinion. Anything that sanitary engineers can do to educate municipal officials—to show them why and how they should treat their sewage—will bring credit to many a backward city and will benefit unmeasurably the profession of sanitary engineering.

Use of Portable Air-Lift for Removing Sludge from Imhoff Tank

BY JOHN W. DEBRUN, JR.

Resident Engineer, Taylorville Sanitary District

In 1926 the Taylorville Sanitary District, of Taylorville, Illinois, completed the construction of a sewage treatment works which included an Imhoff tank and sludge drying beds. However, the plant was not put into operation until 1928 due to certain delays in the construction of the intercepting sewers caused by litigation. In the summer of 1929, a small amount of well digested sludge was removed from the tank. In 1930, after the removal of approximately eight thousand gallons of well digested

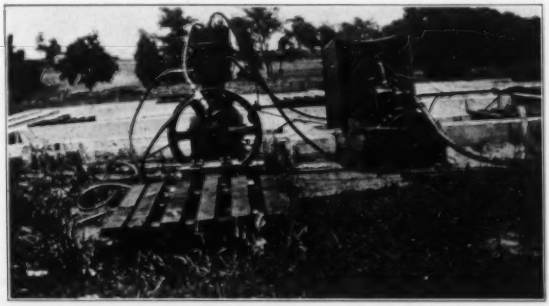


FIG. 1.—Portable Motor and Air Compressor.

sludge, it was almost impossible to remove any additional thoroughly digested sludge with the equipment which had been installed in the construction of the tank. The only sludge that could be removed was that which had been deposited near the outlet pipes. The angle of repose of the sludge adjacent to the outlet pipe was approximately 45 degrees.

The perforated pipes which had been placed around the outer edge of the sloping bottom of the tank had become clogged and it was impossible to force water through them. We installed additional perforated pipes in different portions of the tank, which we thought would break up the sludge and tend to cause it to slide toward the bottom of the pit. However, the sludge was so heavy that these pipes did very little good. The sludge removed did not compensate for the cost of installing the additional perforated pipes. The sludge that we were able to remove was a mixture of digested and partially digested sludge. Any success that

we had in getting the sludge to the bottom of the pit was offset by the fact that the fresh sludge reached the point of outlet before the digested sludge.

In order that we might be able to remove the digested sludge from all parts of the tank, we constructed a small air-lift. (Fig. 1) We used the air-lift after having tried pumping the sludge. When using a pump it was difficult to move the suction pipes from one position in the tank to another, but inasmuch as there is very little internal or external pressure on the discharge pipe of an air-lift, a pipe that is very light may be used. The discharge pipe of the air-lift is made of standard tin down-spout and to it is attached a one-inch wrought iron pipe which makes the down-spout rigid enough so that it can be readily handled. The top of the discharge pipe is fitted with a one-inch plugged opening to which the air line may be attached. (Fig. 2) In case the discharge pipe becomes clogged the air line is connected to the upper end of the discharge pipe and air is applied, blowing the material back into the tank, thereby cleaning the pipe so that it will operate.

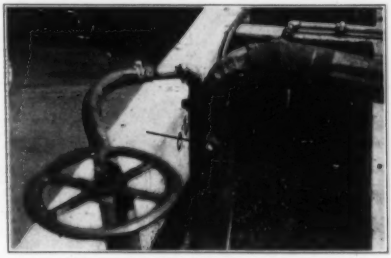


FIG. 2.—Air Line and Vertical Sludge Line, Plugged Opening for Blowback.

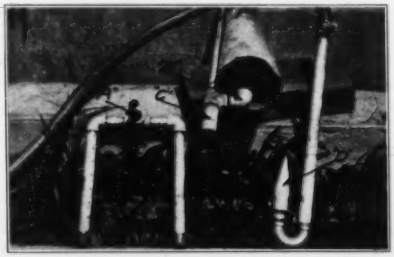


FIG. 3.—Details of Bottom of Air-Lift.

The compressor used was a small portable one, having a capacity of ap-

FIG. 4.—Roof Drain Down-Spout for Discharge of Sludge.

proximately 22 cubic feet per minute. With this amount of air we are able to remove approximately 45 gallons per minute when using a down-spout of four inches internal diameter. The sludge in the tank is too heavy to flow through the discharge pipe, so we found it necessary to dilute it. We tried several methods of applying the liquid before the sludge entered the air-lift. The most successful method was by the attachment of perforated pipes as shown at *A*, Figure 3, in place of the nipple shown at *C*, and pumping water through this pipe line. When the perforated water pipes rested on the bottom of the tank the lower end of the discharge or sludge pipe was seven inches above the bottom of the tank. This, of course, necessitated the removal of the elbow shown

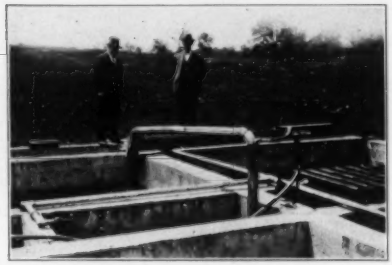


FIG. 5.—Top of Air-Lift.

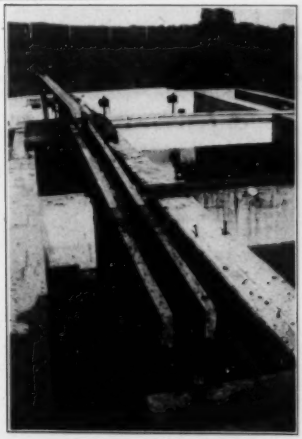


FIG. 6.—Discharge of Diluted Sludge.

FIG. 7.—Discharge of Undiluted Sludge.

at *B*, and plugging of the tee to which this elbow was fastened. We then placed an additional pipe with a strainer and U connection as shown at *D* in the lower end of the air-lift discharge pipe and applied the air through the hose. The strainer acts both as an air-diffuser and keeps the sludge and grit from backing into the air-lift when the pressure is released. By this method the sludge was diluted before it entered the discharge pipe. The lower end of the discharge pipe was made larger to give sufficient room for the passage of the sludge after the air-pipe and diffuser was in position.

To date we have found the apparatus quite successful. It is very easily moved and regardless of the consistency of the sludge we are able to take the lower portion of sludge at any point in the tank. The entire apparatus is very light and can readily be moved by two men. The method of spouting the sludge after it is lifted to the top of the tank is shown in Figures 4 and 5, which in this case is partially done by the attachment of a length of down-spout to the upper end of the air-lift, the connection to the air-lift being made by a piece of hose or flexible tubing. The flow from this pipe is in turn discharged into a wooden trough and into the six-inch cast iron pipe which was installed in the construction of the tank.

Figure 1 shows a general layout of the equipment with which the experiments were made, including the compresser and the motor used in driving the compressor, as well as a small water pump which was attached to the compressor for furnishing water to dilute the sludge. The plant being located some distance from the city limits, city water was not available.

Figure 6 shows the discharge of diluted sludge. Figure 7 gives some idea of the consistency of the sludge when it was being lifted before dilution. However, we do not try to operate the equipment without diluting the sludge, since the apparatus is very much more efficient if the sludge is diluted before it enters the uptake pipe of the air-lift. The experiment having proved satisfactory, we propose to install a more modern power plant and compressor.

Editorial

Gas from Water

For some time sewage chemists and sanitary engineers have been puzzled by reported yields of gas from sewage sludge in amounts by weight greater than the loss of volatile matter, as determined. Two valuable papers are published in this issue, by Dr. Rudolfs and Dr. Buswell, dealing with the amount of gas that may be expected from sewage sludge, and presenting data on gas yield from pure chemical substances.

Dr. Rudolfs is somewhat skeptical of reported high yields of gas from sewage sludge, particularly when the weight of gas is appreciably more than the weight of volatile matter decomposed. He recovered 91, 101 and 103 per cent, by weight, of the volatile matter decomposed. These results indicate a quantitative recovery of all of the lost volatile matter, within the limits of sampling and analytical errors. It may seem quite remarkable that all of the volatile matter decomposed is recovered as gas, but Dr. Buswell has obtained considerably greater recoveries than 100 per cent of the weight of pure chemical substances, and he cites results from several separate sludge-digestion plants where more than 100 per cent recovery has been reported. Aurora showed a recovery of gas amounting to 125 per cent of the loss of volatile matter.

Drs. Buswell and Boruff have shown by carefully controlled laboratory experiments that it is possible to recover, as gas, 123 per cent of the weight of butyric acid decomposed, 111 per cent of cellulose, 109 per cent of starch and lower amounts for casein and peptone. Based on composition, they calculate that fats should yield 133 to 154 per cent of their weight as gas, crude fiber 111 per cent and protein 76 per cent.

These data lead Drs. Buswell and Boruff to believe that similar high yields of gas from sewage sludge may be due to decomposition of fats and soaps, with water attached to the molecule to furnish the excess weight.

Although theoretically this reaction has been demonstrated, one may question whether or not some consistent error in sampling and analysis of sludge might not be responsible for high gas yields. Dr. Rudolfs and his co-workers have indicated that the methods of determining volatile solids in fresh sludge may not include all of the actual organic matter present. Dry sludge solids held at 100° C. may apparently lose appreciable weight. The question therefore arises—does digested sludge also lose an equal or greater amount of matter at 100° C.?

A comprehensive study of the significance of the volatile matter deter-

mination would be of great value, particularly in connection with sludge digestion experiments under controlled conditions. Dr. Rudolfs has published some data on this subject and it would be desirable to have more contributions of this type, in view of the importance of the question. Dr. Buswell has also studied this problem, and in Illinois State Water Survey *Bulletin* **29,** page 49, he discusses the correction for undetermined volatile matter, particularly in supernatant liquor, where the loss may be very great. On digested sludges the error is obviously not so large. On fresh sludge the error would probably be even less, as based on volatile ammonium compounds, but there may be other losses, not so easily demonstrated. A thorough study of the vagaries of the volatile matter determination should take account of the original material and the products.

Recently Dr. Rudolfs has stated "Our studies indicate that without doubt there are errors in the solids determination, as practiced now in laboratories, on sludge samples."

Sampling of raw sludge also tends to add to the difficulties of establishing a reliable value for the amount of gas produced by an indicated loss of volatile matter.

It would therefore seem to be desirable to have more data under carefully controlled conditions so that the sampling and analytical errors are so negligible as to make the conclusion inevitable that a considerable amount of gas is produced from water in sludge digestion tanks. The theoretical possibilities have been clearly demonstrated by Dr. Buswell, but the proof in the case of large operating plants is not so clear, in view of some of the factors we have discussed.

Proceedings of Local Associations

Michigan Sewage Works Association
Eighth Annual Meeting

East Lansing, March 31–April 1, 1932

The Eighth Annual Meeting of the Michigan Sewage Works Association was held March 31 to April 1, 1932 at Michigan State College, East Lansing. This meeting was generally considered as the most successful of any yet held by the Michigan organization. There were approximately 75 registrations. An innovation this year was the short course in laboratory work given at Michigan State College on the two days preceding the conference. This work was given under the direction of Professors Theroux and Eldridge. Twenty-three were enrolled for the course.

Several interesting and instructive papers were presented. Mr. N. G. Damoose gave a description of the first year's operation of the Grand Rapids plant, dwelling particularly on the results obtained and methods of operation. The paper was very well prepared and presented in interesting form.

Through the courtesy of the Sanitary District of Aurora, Illinois, Mr. W. A. Sperry, Superintendent of the Aurora Treatment Works, was present and presented a very interesting description of the operation of the Aurora plant. Of particular interest and significance was his description of controlling the plant operation to conform to the requirements of the stream receiving the plant effluent.

Mr. E. C. Schneider, a graduate student of Michigan State College, presented a paper showing the results obtained on a small trickling filter under different conditions of loading, and the degree of purification obtained at various depths.

Mr. James R. Rumsey described the methods employed at Grand Rapids to promote public interest in their plant and insure popular interest and support. The talk was illustrated by slides, showing views of grading and planting operations. This talk inspired considerable discussion among those in attendance.

Following a talk on bacteriology by Professor Mallmann at a previous meeting, many members requested that he be secured for another paper at this meeting. This was done and Mr. Mallmann's second talk was equally interesting and instructive.

A very instructive talk on the digestion of sewage solids was presented

by Dr. A. J. Fischer. Many of the problems met in the operation of sludge digestion tanks were discussed and the best methods of overcoming difficulties presented.

At a business meeting the following officers were elected for the ensuing year: *President*, Mr. John Jellema, Holland; *Vice-President*, Mr. R. E. Kelley, Sturgis; *Director*, Mr. E. F. Eldridge, East Lansing; *Secretary-Treasurer*, W. F. Shephard, Michigan Dept. of Health, Lansing.

The new President appointed a committee on laboratory practice and a second committee on standardization of cost records. Mr. J. R. Rumsey of Grand Rapids and H. A. Olsen of Pontiac were appointed as members of the Board of Control of the Federation of Sewage Works Associates.

W. F. SHEPHARD, *Secretary*

Maryland-Delaware Water & Sewerage Association Sixth Annual Conference

Cumberland, Maryland, April 12-13, 1932

Ninety two people attended the Sixth Annual Conference of the Maryland-Delaware Water and Sewerage Association, held in Cumberland, Maryland, April 12 to 13, 1932. While the attendance was somewhat below normal, everyone agreed that the meeting was the best ever held by the Association.

Mr. Harry R. Hall, President of the Association, presided over the first and Mr. R. C. Beckett, the incoming President, over the second session. Mr. Abel Wolman conducted the discussion of the question box topics.

The first paper was presented by Professor Lewis V. Carpenter of the West Virginia University, on "Elementary Sewage Disposal." Professor Carpenter traced the methods of sewage disposal from the time of Moses to the present day. Brief descriptions were given of the various units of treatment plants, their functions and uses.

Mr. George L. Hall, Division Engineer of the Maryland State Department of Health, in his discussion of this paper stated that there were 38 sewage treatment plants in Maryland of which 13 were institutional plants. The need for competent operators was stressed.

"Admission of Industrial Wastes Into Sewerage Systems," H. M. Freeburn, District Engineer, Pennsylvania Department of Health. Industrial wastes were discussed as being divided into four classes: (1) those that can be admitted to the sewerage system without preliminary treatment; (2) those that can be admitted after flow adjustment without any preliminary treatment; (3) those that can be admitted after they have been

given preliminary treatment, and (4) those that should be excluded from the system. The speaker concluded his paper by saying "If you are right, fair and just, and have properly presented your case showing the need for industrial waste treatment to responsible industrial plant executives, there will be little trouble."

In the discussion of this paper prepared by J. B. Gordon, Sanitary Engineer, Washington, D. C., an account was given of the disintegration of a concrete interceptor in Washington due to the entrance of trade waste. The waste from a yeast factory was harmless, but in combination with the bacteria in the domestic sewage caused the sulphate content to be broken down and hydrogen sulphide to be produced. Arrangements have been made to chlorinate the domestic sewage prior to the entrance of the waste into the interceptor.

A symposium describing the method of controlling the pollution of streams in their respective states was given by R. C. Beckett, W. L. Stevenson, E. S. Tisdale and Abel Wolman, State Sanitary Engineers of Delaware, Pennsylvania, West Virginia and Maryland, respectively.

Further papers dealt with water-supply topics.

At the business meeting of the Association, the following officers were elected: *President*, R. C. Beckett, Dover, Delaware; *1st Vice-President*, B. E. Beavin, Annapolis, Maryland; *2nd Vice-President*, J. S. Strohmeyer, Baltimore, Maryland; *Secretary*, A. W. Blohm, Baltimore, Maryland; *Treasurer*, E. S. Hopkins, Baltimore, Maryland; *Executive Committee*, S. N. Van Trump, Wilmington, Delaware.

A. W. BLOHM, *Secretary*

New England Sewage Works Association
Fourth Annual Meeting

Boston, Mass., April 25, 1932

The Fourth Annual Meeting of the New England Sewage Works Association was held at the Hotel Bradford, Boston, Mass., Monday, April 25, 1932. One hundred and four members and guests were registered for the meeting and eighty attended the annual dinner.

Exhibits of sewage works equipment were presented by the following manufacturers: Dorr Company, Lord & Burnham, Link-Belt Co., Wallace & Tiernan, Norton Company, Pacific Flush-Tank Co.

These exhibits were displayed in the meeting room and were the source of much interest and information to those attending the meeting.

Registration started at 10:00 A.M., the meeting being called to order at

10:30 A.M. by the President, Warren J. Scott. The first paper of the morning session "Industrial Wastes in Relation to Sewage Treatment," was presented by Stuart E. Coburn. In the absence of Mr. Coburn, his paper was read by Mr. Almon L. Fales. The second paper was presented by Mr. Bayard F. Snow, being entitled "The South Essex, Mass., Sewerage System." In order to conserve time the discussion of these papers was deferred to the afternoon session. Mr. John G. Albertson, Consulting Engineer of New York City, presented the third paper, a description of the "New Canaan, Conn., Sewage Treatment Works," a new activated-sludge plant recently placed in operation. Mr. Albertson's paper was illustrated by lantern slides.

Following the presentation of the papers the President opened the business meeting of the Association. The Treasurer's report, showing a balance, as of April 23, of $169.12, was accepted. The President read the report of the auditor, Mr. A. D. Weston, stating the books of the Society had been audited and found correct. The Secretary's report, showing the total membership, as of April 23, to be 123, was accepted.

The first item of business was consideration of the proposed amendments to the Constitution. The President explained that the Executive Committee suggested these amendments in order that the terms of office of the Officers might correspond with the term of the Board of Control of the Federation of Sewage Works Associations. It was voted to amend Article VIII to read;

> Beginning in the year 1933, the Annual Meeting shall be held in the month of October.

It was voted to amend Article VI to read:

> The officers of this Association shall be a President, a Vice-President, a Secretary-Treasurer, and two Directors. The term of office shall be one year. Officers shall be elected at the Annual Meeting in October to take office the following January 1. No officer, except the Secretary-Treasurer, shall serve more than two years consecutively. Officers elected at the Annual Meeting in April, 1932, shall hold office until December 31, 1933.

The President appointed Messrs. Bugbee, Holmes and Carson as a Nominating Committee to prepare nominations for officers for the coming year; the Committee to report at the close of the business meeting.

Mr. Lanphear presented a resolution of the Executive Committee that the Executive Committee be empowered to plan informal meetings or inspection trips between regular meetings of the Association in sections where no regular meeting would be held for some time. After some discussion it was decided to leave the matter of arranging such inspection trips to the discretion of the Executive Committee as they are charged with the duty of planning special meetings by the Constitution.

The President called upon the Nominating Committee to present its report. Mr. Bugbee, Chairman, reported that the Committee nominated for the consideration of the Association the following candidates for office:

President, Roy S. Lanphear, Worcester, Mass.; *Vice-President*, Gordon M. Fair, Cambridge, Mass.; *Secretary-Treasurer*, F. Wellington Gilcreas, Boston, Mass.; *Directors*, Warren J. Scott, Hartford, Conn.; Frederick C. Williams, Pawtucket, R. I.

It was voted that the report be accepted and the nominations be closed. On motion duly made and seconded it was voted that the Chairman of the Nominating Committee cast one ballot for the candidates nominated. This was done and the above declared elected.

The meeting adjourned for luncheon at 1 P.M. No Association luncheon was held, the members gathering for luncheon in the various dining rooms of the hotel and the nearby restaurants.

The afternoon session was called to order at 2:30 P.M. the program being devoted to Round Table Discussion. President Scott called upon Mr. H. W. Clark to discuss the paper on the South Essex Sewerage System, presented at the morning session. Following discussion of the papers presented at the morning session, the time was devoted to discussion of the various topics, as follows: Screens; Removal of Oil and Grease; Operation of Small Treatment Plants; Separate Sludge Digestion.

President Scott introduced Mr. Edward Wright, who gave a brief account of recent visits he had made to various sewage treatment plants in the eastern United States and Canada.

The report of the Committee on Sewage Sampling was deferred until the evening meeting. The afternoon session adjourned at 5:30 P.M.

At 6:30 P.M. the members and guests assembled for the Annual Dinner. Following the dinner a brief musical entertainment was presented. President Scott called on Mr. Lanphear, Chairman of the Committee on Sewage Sampling, who reported that the Committee had prepared its report, copies of which would be sent to each member with the request that criticisms and suggestions be submitted to the Association for consideration and possible inclusion in the final report which would be presented at the next meeting of the Association.

President Scott then introduced Professor John W. M. Bunker, Dept. of Biology and Public Health, Massachusetts Institute of Technology, who gave a most interesting address on the subject of "Stream Pollution and Self-Purification," describing the action of various micro-organisms that function in stream purification. Following his address Professor Bunker illustrated by micro-projection many of the organisms whose functions he had outlined.

The meeting was adjourned at 9:30 P.M.

F. WELLINGTON GILCREAS, *Secretary-Treasurer*

Central States Sewage Works Association
Fifth Annual Meeting

Rockford, Illinois, May 13–14, 1932

The Fifth Annual Meeting of the Central States Sewage Works Association was held May 13 to 14, 1932, at Rockford, Illinois. This was a joint meeting with the Illinois Association of Sanitary Districts, which has held nine annual meetings since its organization in 1924.

The Nelson Hotel was headquarters for the joint meeting and all technical sessions were held in this hotel. The feature of the meeting was the dedication of the new sewage treatment works of the Rockford Sanitary District, which was put into operation in February, 1932. For a number of years the dedication of a new sewage treatment plant has been the feature of the meetings of the Illinois Association.

The wisdom of combining the 1932 meetings of these two groups was apparent from the large attendance and varied program. Joint meetings were held Friday morning, separate meetings Friday afternoon, and joint meetings Saturday. The Friday afternoon session of the Illinois Association was devoted to administrative and legal affairs of the various sanitary districts, of which 17 are now members of the Illinois Association.

The total registration for the meetings was 231. An interesting program of entertainment for the ladies was arranged by the local committee, including a motor trip to the beautiful Rock River Valley, near Oregon, Illinois, and a visit to the statue of Blackhawk, famous chief of the Indian Wars in Illinois.

The first technical meeting was held Friday morning, May 13, with President L. F. Warrick of the Central States Association and President G. J. Boehland of the Illinois Association as presiding officers. The first paper was by Langdon Pearse, entitled "A Quarter Century of Progress in Sewage Treatment." Mr. Pearse traced the evolution of sewage treatment in the Sanitary District of Chicago during the past quarter of a century, and dealt particularly with the recent work directed toward the disposal of sewage sludge by incineration. The next paper was to have been presented by George W. Fuller, but since he was unable to be present, Mr. F. G. Cunningham, of Mr. Fuller's office, discussed "Sewage Disposal Trends in the New York City Region." The Ward's Island and the Hackensack Valley projects were described. The last paper on the morning program was by Adolph Kanneberg, Chairman of the Wisconsin State Commission on Stream Pollution. Mr. Kanneberg discussed "The Rock River Clean-Up Program as a Part of the Interstate and National Program of Stream Conservation." The Rock River flows southerly from Wisconsin into Illinois, so that sewage treatment programs are common to both states. Above

Rockford are located Janesville and Beloit in Wisconsin; Mr. Kanneberg and Mr. Warrick are hopeful of progress in the near future with regard to sewage treatment in these communities.

In the afternoon the first paper, by Lewis S. Finch, State Sanitary Engineer of Indiana, was entitled "Sewage Works Cross Connections." A paper by C. K. Calvert, "The Hourly Variation in Indianapolis Sewage," was read by title. The next paper was presented by L. W. Hunt on "Some Operating Problems of the New Sewage Treatment Plant at Galesburg, Illinois." Data on trickling filters in Wisconsin were presented by E. J. Beatty under the title "Calculation of Trickling Filter Load." The final afternoon paper was by Samuel A. Greeley and C. C. Larson, entitled "Grease Skimming Basins for Sewage Treatment Works, with a Description of the Installation and Operation of the Basin at the Springfield Plant."

At the close of this session, about 4:00 P.M., all members were taken to the site of the new treatment works, where the dedication services were held under a large tent. The weather was ideal and the addresses by G. J. Boehland, President of the Rockford Sanitary District, Samuel A. Greeley, Consulting Engineer and Judge Fred Carpenter, in dedication of the plant, were impressive and significant of the occasion. The construction cost of the intercepting sewers was $2,200,000 and of the treatment works $435,000. The latter comprise a main pumping station, grit removal tanks (detritors), primary settling tanks, sludge digestion tanks, sludge storage tanks, sludge beds, sludge pumping station and laboratory. The layout of the plant is unusually attractive and effective landscaping added materially to the favorable impression created on all visitors.

After the inspection of the plant, members of the associations returned to the hotel, where the annual banquet was served. The toastmasters were Gust. J. Boehland and L. F. Warrick. The response to the address of welcome was made by A. F. Beaubien, Attorney for the North Shore Sanitary District. Mr. Beaubien's clever quips provided the yeast to leaven the more serious addresses which followed. Harking back to the slogan of personal cleanliness of several decades ago, "Good morning, have you used Pear's soap?" Mr. Beaubien remarked that the civic slogan of the present day is "Good morning, have you had your sewage treated?" This question will be asked with more insistence in the next decade.

The programmed addresses for the evening were by Dr. C. A. Harper, State Health Officer of Wisconsin, on "Stream Sanitation, the Challenge of Our Time," and by W. W. DeBerard, Western Editor of *Engineering News-Record*, on "Where Are We?" Mr. DeBerard deplored the present national tendency toward restriction of the construction of new public works. Both he and Dr. Harper complimented the Rockford Sanitary District on the completion of such a large undertaking in this time of economic depression.

Entertainment by a string trio and "Two Graces" from Chicago ended the evening's program.

The technical program Saturday morning included seven papers, as follows:

"Chemical and Physical Characteristics of Sludge." By Darrell Althausen and Arthur M. Buswell, Illinois State Water Survey.

"Development of Power from Sewage Sludge Gas." By W. B. Walraven, Springfield, Illinois.

"Practices of Industrial Waste Disposal in Milwaukee." By H. M. Heisig.

"Profitable Preparation and Sale of Digested Sludge as Commercial Fertilizer." By Myron W. Tatlock, Dayton, Ohio.

"Proposed Disposal of Sewage Grit, Coarse and Fine Screenings by Incineration." By Darwin W. Townsend, Milwaukee, Wis. Published in this issue.

"Grease Solvents for Sludge Extraction." By O. J. Knechtges, Madison, Wisconsin.

"The Removal of Suspended Matter and the Gas Production of the Imhoff Tanks at Decatur, Illinois." By W. D. Hatfield.

After a Swedish Smörgasbord luncheon, the following papers were presented in the afternoon:

"A Comparison of Methods of Aerating Sewage." By H. E. Babbitt, Prof. of Sanitary Engineering, Univ. of Illinois.

"Overloaded Trickling Filter Plant Relieved by Sedimentation and Chlorination of Excess Flow." By A. L. Tholin, Downers Grove, Illinois.

"Four Years' Operating Experience Using Imhoff Tanks and Trickling Filters at Bloomington-Normal Sanitary District." By Harry E. Wilson.

"The Attitude of Industry Toward Stream Pollution." By C. M. Baker, Sanitary Engineer, American Paper Manufacturer's Association.

The new officers elected for the year 1932–33 were as follows:

Illinois Association of Sanitary Districts—*President*, A. O. Lindstrum, Galesburg; *Vice-President*, F. S. Simms, DeKalb; *Secretary-Treasurer*, Gus Radebaugh, Urbana.

Central States Sewage Works Association—*President*, C. K. Calvert, Indianapolis, Ind.; *First Vice-President*, H. F. Ferguson, Springfield, Ill.; *Second Vice-President*, M. Starr Nichols, Madison, Wis.; *Secretary-Treasurer*, Gus Radebaugh, Urbana, Ill.

Invitations were extended by the Galesburg Sanitary District for next year's meeting of the Illinois Association of Sanitary Districts and by Indianapolis for next year's meeting of the Central States Sewage Works Association.

GUS RADEBAUGH, *Secretary*

California Sewage Works Association Spring Conference—Yosemite Valley

May 20–21, 1932

8:30 A.M., Friday, May 20, 1932

About 100 members and guests assembled at the Yosemite Park Activated Sludge Plant located south of Merced River near Bridal Veil Falls. The plant location was chosen to meet rigorous requirements of freedom from odors and noise, and is out of sight of roads and trails. It consists of plain hopper-bottom settling tank; 4 aeration units equipped with Norton plates (air being furnished by 2 G. E. centrifugal blowers), and designed for spiral-flow type aeration—one unit can be used for reaeration; 2 Dorr clarifiers in series, the second serving also as a chlorine contact tank; an automatic Wallace & Tiernan chlorinator for regular use, with a portable machine for standby emergency service; separate sludge-digestion tanks with gas collection and heating but no mechanical stirring; a sludge-thickening tank for raw or activated sludge; and a glass-covered sludge drying bed.

The plant is well arranged, neatly kept and aroused favorable comment from members. Particular comment was heard on the use of continuous streams of effluent from the two clarifiers for sampling at a table similar to that at a water filter plant, and a vacuum gauge with colored liquid, at the same table, to indicate the chlorine feed at any given time. A float gauge on the effluent weir gives readings of sewage flow leaving the plant.

A caravan was formed at the plant, led through typical camp grounds of the Park and stopped at the incinerator where garbage-can washing apparatus and a can-baling machine were demonstrated to the members.

Members met in informal groups for lunch.

Afternoon Session, May 20, 1932

The meeting was called to order by President Allen. Harry B. Hommon, Chairman of the Committee on Program and Local Arrangements, was introduced and he in turn introduced Col. C. G. Thompson, Park Superintendent, who welcomed the California Sewage Works Association to the Park and praised the work of Mr. Hommon in sanitation of parks, mentioning with particular pride the new sewage disposal plant.

An excellent paper, "Activated Sludge Sewage Treatment Plant in Yosemite National Park," was read by Russell C. White, Operator. Discussion following this paper included (*a*) "Griffith Park Experimental Station, Los Angeles," by S. M. Bennett, Chief Operator; (*b*) "Activated Sludge Sewage Treatment Plant, Lodi," by Fred W. Post, Supt. (read by

the secretary); (*c*) "Activated Sludge Sewage Treatment Plant, Pasadena," by Alfred W. Wyman, Supt.; (*d*) "Activated Sludge Sewage Treatment Plant, Salinas," by T. R. Haseltine; (*e*) "Activated Sludge Sewage Treatment Plant, Los Angeles Sanitation District," by A. P. Banta; (*f*) "Activated Sludge Treatment Plant, Grand Canyon National Park, Grand Canyon, Arizona," by Hilliard Hall, Operator (read by H. B. Hommon).

Others taking part in the discussion were President Allen, A. J. Smith and W. C. Roberts. The latter had just returned from Phoenix, Arizona, where he reported excellent results were being obtained with paddle aeration in addition to diffused air, using about 0.25 cubic foot of free air per gallon.

The symposium "Unusual Experiences in the Operation of Sewer Systems," by F. A. Batty, Los Angeles; F. D. Bowlus, Los Angeles County; J. C. Albers, Glendale; C. M. Hoskinson, Sacramento; T. F. Eastman, Oakland; and W. F. Rantsma, Fresno, brought forth many interesting and instructive observations. An entertaining talk on political experiences was given by S. H. Davis of Glendale. D. E. Perry of San Anselmo asked for information on per capita cost of sewerage and sewage disposal at various places and was given the information in a few instances.

The meeting adjourned until 9 A.M. May 21.

Evening Outdoor Barbecue, May 20

One hundred and eight members and guests attended the outdoor barbecue at Indian Caves. After a hearty repast, President Allen introduced H. B. Hommon and turned the evening over to him. Park officials who contributed so freely of their time and energy to make the meeting a success were introduced. Dr. D. Tresidder, general-manager of the Yosemite Park and Curry Company, gave a delightful talk offering fullest coöperation of the Company in making the visit enjoyable. He referred to the sewage disposal problem as having been "solved" about every ten years in the history of the Valley and expressed the hope that the new plant would prove the final solution.

Bert Harwell, Park Naturalist, was then introduced. He entertained with a talk on the formation of Yosemite Valley, led community singing, presented his nephew in violin solos, a quartet in popular songs and gave a few whistling solos. He also chose a place to view the "fire fall" from Glacier Point at 9 P.M. This was especially arranged for our Association through the courtesy of park officials and was a fitting climax to an eventful day and evening.

After the regular program some of the members were shown though the Park Museum which was opened for their benefit. Others visited the bear pits to watch the evening feeding of the bears.

Morning Session, May 21, 1932

The meeting was called to order by President Allen.

J. C. Albers, Chairman, reported for the Legislative Committee that five meetings had been held with the Legislative Committee of the League of California Municipalities on Sewer Rental, and a report would be prepared for the Fall Meeting.

John Spencer, Chairman, reported some difficulty with publicity to date. He urged each member to give his local paper a short story of the Yosemite meeting.

Professor C. G. Hyde, Chairman, read the report of the Committee of Award of Merit for 1931, which decided in favor of Pomona, largely because of the development of revenues from sewage and also for its excellent records with honorable mention to Escondido. President Allen announced that the Board of Directors had decided in the absence of a contribution as received in past years to award $25 cash from the Association funds. A. M. Rawn moved that the Association grant the cash award and it was seconded and carried. The Secretary explained that in view of previous cash awards the Committee had announced that a cash award would be given and the Board felt that was a promise which should be kept by the Association.

In answer to a question from the floor, President Allen stated that the cash award was given to the operator of the plant and not to the city.

H. F. Gray reported for the Resolutions Committee, consisting of L. B. Reynolds, C. A. Smith and himself, presenting written resolutions in memory of two of our deceased members, Philip Schuyler and Andrew M. Jensen. These resolutions were adopted and the members stood silent for a few moments in respect to their memory.

Mr. Gray also paid a high tribute to Professor Charles Gilman Hyde for his many years of pioneer work in sanitary engineering in the west. Mr. Gray was a member of the first graduating class in sanitary engineering at the University of California a quarter of a century ago and the progress during the past 25 years he considered truly remarkable, and largely due to the original work of Prof. Hyde.

Prof. Hyde responded briefly by telling of the satisfaction he had of seeing his former students at work in the sanitary engineering field, which he said was the greatest satisfaction men like Prof. Reynolds at Stanford and himself could get from their teaching.

Mr. Alva J. Smith spoke briefly of the progress in California during the ten years since he came to the state. He noted that we had a paper on one activated-sludge plant and discussion by operators from six others. He believed there was not a single activated-sludge plant in California 10 years ago. When corrected, Folsom Prison having constructed a plant in 1917–18, President Allen interrupted to remark that never having been

in there Mr. Smith, of course, could not have been expected to know of the plant.

The Secretary was instructed to send suitable letters to the local committee, park officials and company officers who did so much to make our visit to Yosemite a pleasant and profitable one.

Papers were presented as follows: (1) "Activated Sludge Sewage Treatment Plant at Folsom Prison," by L. E. Rushton; (2) "Odor Control at the Whittier Sewage Treatment Plant," by Alva Smith; (3*a*) "Digestion of Bar Screenings," by A. M. Rawn. Discussed by F. A. Batty and T. R. Haseltine; (3*b*) "Digestion of Garbage in Beccari Cells with Analogies to Sludge Digestion Problems," by Chas. Gilman Hyde. Discussed by J. C. Albers and A. M. Kivari; (4) "Improvements at Sewer Farm at Tulare," by W. M. Brown, City Manager; (5) "New Thoughts in Sedimentation of Sewage," by Chester A. Smith; (6) "New Thoughts in Sludge Digestion and Disposal," by R. F. Goudey.

President Allen announced that owing to the short time available the papers by C. A. Smith and R. F. Goudey would be printed as soon as possible and time allowed for their discussion at the San Diego meeting in September.

The meeting adjourned at 12:30 P.M.

Respectfully submitted,

E. A. REINKE, *Secretary*

Reviews and Abstracts

H. W. STREETER

Progress in the Knowledge of the Biochemical Oxygen Demand

By Dr. F. Sierp and F. Fransemeier

Tech. Gemeinde, **34**, 233–9, 250–3, 260–3, 271–5, 289–93, 301–5, 313–7 (1931)

Abstracted by G. P. Edwards

The biochemical oxygen demand determination has been developed through physical and chemical methods to the modern biological ones. The five biological methods which depend on the fact that organic matter can be decomposed by microörganisms which require oxygen are: 1, relative stability; 2, nitrate; 3, dilution; 4, direct (gasometric); 5, combined method.

The relative stability test as used in the Weldert-Spitta methylene blue method is not accurate, as the methylene blue exerts a toxic action and the dye is precipitated by insoluble and colloidal material. The nitrate method developed by Lederer uses undiluted sewage but it has the disadvantage of requiring a foreign substance which must first be decomposed in order to produce oxygen. The oxygen concentration varies considerably during the determination. The dilution method imitates the processes taking place in nature and the oxygen needed by the organisms is supplied in a form which they can easily use. Unlike natural conditions, however, the oxygen supply cannot be replenished and the oxygen concentration varies during the determination. To avoid this great variation in oxygen content, it has been proposed to select a dilution so that there is at least 6.0 p. p. m. dissolved oxygen present at the end of the test. Different dilution waters give different results, therefore, various artificial waters have been proposed. The greatest disadvantages of the method are that a large number of bottles are needed, and the samples used are not available for other tests, such as nitrogen determinations.

The dilution method may be used in two ways for field work. In Meyer's method, the sample is measured in a calibrated beaker and added to a known amount of dilution water which is carried in bottles and which is kept cool in an insulated box. Each dilution bottle requires a separate measuring beaker. In Sierp's method, the sewage is measured in a pipette and added at the bottom of the bottle carrying the dilution water. In this way, any dilution can be made up.

In the direct method, gaseous oxygen is added to the undiluted sewage.

The sample after determination of B. O. D. can be used for the determination of nitrogen compounds and other substances. If the concentration of organic matter is too high to permit biological action, the sample may be diluted 1:1 or 1:2 and the B. O. D. determination made on the diluted sample. In the same way a combination of the nitrate method and dilution method or the nitrate method and the direct method may be used.

The apparatus used for the direct determination of B. O. D. has been improved by substituting glass for rubber stoppers and tubing. Florence flasks are used instead of Erlenmeyers so as to increase the surface exposed to the gas. The samples are agitated by a shaking apparatus which operates periodically by clockwork. For sewages, shaking every three or four hours is sufficient but for sludges or strong industrial wastes, shaking is necessary every hour. Saturated salt solution containing 5 per cent sodium hydroxide is satisfactory as a liquid seal. The alkali absorbs the CO_2 which is formed. H. Bach suggests that gases such as methane and hydrogen may be formed and cause errors in gas readings. However, these gases are formed only under anaerobic conditions. If it is desirable to determine the CO_2, a mercury seal can be used.

The B. O. D. determination by the dilution method should not be made on a raw sewage because of the difficulty in obtaining a true sample and because the degree to which particles are attacked depends on the size, since the greater the size, the smaller the surface in proportion to the mass. The sampling error is practically eliminated in the nitrate and direct methods but it is better to make a B. O. D. determination of the suspended matter and of the settled sample separately. Biological plant effluents should be settled for two hours before determining the oxygen demand.

Bach believes that air should be used instead of pure oxygen in the direct method because the latter is not found in nature and because its physiological action may be different from that of air. He also believes that the excess pressure of 0.01 to 0.05 atmosphere may affect results. However, greater variations of barometric pressure occur naturally. Since the methods now used for the determination of oxygen demand do not accurately imitate natural conditions but only set up standard conditions which can be reproduced elsewhere, it was decided to use oxygen instead of air, especially for the five-day demands. Neave and Buswell have shown that pure oxygen used in aerobic biological processes stimulates the action rather than retarding it. A comparison of the direct method, using oxygen and air, with the dilution method shows that in all cases, the results were so nearly the same that the oxygen could have exerted no sterilizing action.

The immediate demand, which is usually satisfied in one hour, should be determined for strong septic sewages or organic industrial wastes but it may be neglected in normal fresh domestic sewage. The solubility of oxygen in biologically decomposed sewage seems to be slightly less than

theoretical but the difference is so small, it can be neglected. In most cases, it is more important that the temperature be kept constant, as a change of 1° C. means about 1 cc. change in volume when 273 cc. of gas are used. The dilution and nitrate methods are usually run at 20° C. It is very important to maintain this temperature for 1- or 2-day demands but in 20-day periods, the main reactions are usually completed before the expiration of the time so that temperature variations from 18° to 22° C. may be permitted. The barometric pressure is just as important as the temperature in the direct method and should be determined when making gas measurements.

Sewages containing sterilizing agents or which have too high or too low a pH offer difficulties in determining the B. O. D. The pH can easily be corrected by neutralization, preferably with a buffer such as $NaHCO_3$. The neutralized sewage must be seeded with sewage containing a sufficient number of suitable organisms. Sewages containing bacterial poisons are more difficult to handle. Some sterilizing agents paralyze the protozoa fauna and cause the bacteria to multiply. This is important from the standpoint of the choice of preservatives. Oxygen demands made on liter samples of domestic sewage treated with 25 cc. H_2SO_4 (1:3) and 25 cc. formaldehyde showed that the sample treated with H_2SO_4 was not sterilized. An active bacterial flora was always present and there was a continual oxygen absorption as well as a change in nitrogen compounds. The sample treated with formaldehyde was completely sterilized, the small amount of oxygen absorbed being due to chemical reactions. Another series of samples which contained per liter (1) 2 cc. H_2SO_4 (1:3), (2) 50 cc. H_2SO_4 (1:3) (3) 10 cc. H_2SO_3 (5% SO_2), (4) 3 cc. formaldehyde, (5) 3 cc. chloroform, (6) 2.5 gr. NaOH and (7) a sample boiled 5 minutes, were run by dilution and direct methods. Sulphuric acid in amounts up to 50 cc. per liter was not satisfactory as a preservative for long periods. Sulphurous acid was more effective. Boiling was effective for short periods.

The results obtained by the direct and dilution methods were nearly the same, except that by dilution the action of the sterilizing agents was reduced. The sample treated with formaldehyde had a 3-day demand of 866 when a 1 per cent solution was used. The untreated sewage had a 3-day demand of only 175 p. p. m. The formaldehyde in the dilute solution was apparently easily oxidized. Chloroform, formaldehyde and NaOH were quite effective in the direct method for short periods. Concentrated organic wastes such as from distilleries, breweries and dairies which contain no bacterial poisons, but whose sterilizing action depends on excessive concentration, may be diluted 1 : 1 with water. If poisons are present, the waste should be diluted with sewage. The degree of dilution depends on the concentration of the poison. This combination of direct and dilution method is useful in determining whether a waste can be treated biologi-

cally. Concentrated organic wastes which have a tendency to become acid during the B. O. D. determination can be neutralized with NaHCO.

A number of samples using the direct, dilution and nitrate methods showed that the results obtained by the direct and dilution methods were the same but those from the nitrate method were much lower. The increase and following decrease in ammonia content was the same in both the direct and dilution method. The conversion of ammonia to nitrate depends upon the concentration of organic matter and the presence of nitrifying organisms. Too high a concentration of organic matter prevents nitrate formation.

The decomposition of phenol was investigated by the direct and dilution methods. In samples of domestic sewage containing 200 p. p. m. phenol, no phenol was decomposed in the first day but 80 per cent was destroyed in the next 24 hours and the remaining 20 per cent in the following 24 hours, in all cases. Possibly, in high concentrations, a definite type of organism must be developed to decompose the phenol. The decomposition of phenol is not proportional to the increase in oxygen demand. Since the phenol was decomposed in three days, one would expect that the additional oxygen consumption in each case would be the same. However, by the dilution method the 3-day B. O. D. for sewage was 98 and for sewage-phenol mixture, 444. In twenty days the values were 318 and 760, respectively. Another series of experiments showed that under anaerobic conditions phenol was not destroyed in 76 days and in the presence of nitrates the decomposition of phenol was delayed but was complete in 21 days. Aerobically, the phenol was decomposed in three days.

The pH and the concentration and kind of salts present are important in nitrate formation. The nitrifying organisms are active between pH 5.6 and 10.3 with an optimum condition at pH 8.3 to 9.3. The presence of $NaHCO_3$ which buffers well about pH 8.4 favors the activity of these organisms. According to Waksman, nitrifying bacteria need CO_2 for the synthesis of cells. Theriault traces the lack of nitrification in the direct method to the fact that the CO_2 is removed by the caustic. The removal of CO_2 does not proceed fast enough to keep the atmosphere above the liquid free from CO_2. This absence of nitrification is probably due to the high partial pressure of oxygen since complete nitrification can be obtained in practically pure oxygen with nitrifying sludge. The B. O. D. was run on samples of sewage for six days and on the seventh, 10 cc. of Essen-Rellinghausen (Plant I) activated sludge which had been aerated 10 days was added to each 100 cc. of sewage. No nitrification occurred during the first six days, but with the addition of sludge, rapid nitrification took place even with pure oxygen.

The B. O. D. of sludges can be determined easily by the direct method. Determinations were made on fresh, digested and activated sludges.

Samples of 10–25 grams (100 grams of activated) were diluted with 90 or 75 grams of water and ground in a mortar until all would pass through a 1 mm. sieve. Fifty grams of this sludge was diluted with 150 cc. water and with constant stirring, 100 cc. of the mixture was drawn off into a flask. About 5 cc. of saturated $NaHCO_3$ solution was added as a buffer. Air was used instead of oxygen. The oxygen demands are shown in Table I. Cal-

TABLE I

	Fresh Solids from Rellinghausen I % Solids 3.96 % Vol. 65.5 Mg. O_2 Demand per			Fresh Solids from Rellinghausen II % Solids 8.09 % Vol. 50.3 Mg. O_2 Demand per			Digested Sludge from Rellinghausen I % Solids 14.28 % Vol. 44.8 Mg. O_2 Demand per			Activated Sludge Rellinghausen I % Solids 2.84 % Vol. 60.1 Mg. O_2 Demand per		
Days	1000 G. Wet Sludge	1 G. Dry Solids	1 G. Organic Solids	1000 G. Wet Sludge	1 G. Dry Solids	1 G. Organic Solids	1000 G. Wet Sludge	1 G. Dry Solids	1 G. Organic Solids	1000 G. Wet Sludge	1 G. Dry Solids	1 G. Organic Solids
1	3460	85.8	131.0	4330	53.7	106.5	3840	26.9	60.0	787	27.7	46.1
2	5500	138.8	211.7	6530	80.8	160.2	6420	45.0	100.7	1438	50.7	84.2
3	9220	232.5	354.7	10700	132.3	262.7	10420	73.0	163.0	2183	76.8	128.0
4	11420	288.7	440.5	13600	168.2	334.0	12020	84.1	187.5	2455	86.5	143.7
5	13030	329.0	502.0	15970	197.5	392.0	13500	94.5	210.7	2687	94.7	157.5
10	18020	455.0	693.0	26330	326.0	647.5	22450	157.2	350.7	3410	120.0	199.5
15	20740	523.5	800.0	32130	397.8	790.0	28130	197.0	438.0	3960	139.3	231.8
20	22330	564.5	863.0	34600	428.0	852.0	31800	222.5	497.0	4360	153.4	255.8
25	23770	600.5	918.5	36180	447.5	890.5	33770	236.5	527.5	4680	164.9	274.1
28	25100	634.5	970.0	37070	457.8	910.0	34870	244.2	545.0	4800	1o8.9	281.0

culated on the basis of volatile solids, the B. O. D. of the two fresh sludges are nearly the same. The results of nitrogen determinations are shown in Table II. Whereas, in most cases all the ammonia was converted to nitrate in 28 days, the organic nitrogen in the fresh solids from Rellinghausen II

TABLE II

	Initial—P. p. m.				Final—P. p. m.			
	Organic N_2 Calculated as NH_3	NH_3	N_2O_5	Total	NH_3	N_2O_5 Calculated as NH_3	Total	NH_3 Formed from Organic Nitrogen
Fresh Solids I	1452.0	316.0	0	1768.0	0	824.0	824.0	508
Fresh Solids II	2400.4	217.6	0	2618.0	512.0	4.0	516.0	298.4
Digested Sludge I	3243.0	306.0	0	3549.0	0	555.0	555.0	249.0
Activated Sludge I	863.6	47.6	0	911.2	0	279.0	279.0	231.4

was converted to nitrate, with ammonia as an intermediate product. The ammonia increased from 218 to 512 p. p. m. The fact that only 4 p. p. m. nitrate was formed indicates that the real nitrification period had not set in, although it was completed in the other sludges.

Digested sludge from different treatment plants was compared in another series of experiments. Three samples of digested sludge were obtained from Rellinghausen. The sludge from Tank A was mostly fresh solids from Plant II. The tank is heated during the winter and the sludge is well digested. The sludge from Tanks B and C contained fresh solids from Dorr

TABLE III

	Rellinghausen I				Hattingen		Menden			
	Digested Sludge Tank A	Digested Sludge Tank B	Digested Sludge Tank C	Digested Sludge Drying Beds	Digested Sludge Imhoff Tanks	Digested Sludge Drying Beds	Digested Sludge Imhoff Tanks	Digested Sludge Drying Beds	Experimental Digested Sludge Liquid	Experimental Digested Sludge Drying Bed
Initial—Solids, %	14.5	4.7	6.7	44.9	18.9	43.6	18.7	39.0	18.9	49.7
Free NH in 100 Gm. Sludge, Mg.	29.9	44.5	61.3	73.0	23.8	39.1	29.4	38.0	91.0	83.4
pH	7.1	7.2	7.2	7.1	7.2	7.1	7.1	7.3	7.1	7.2
Volatile Solids, %	39.0	53.5	49.1	35.5	39.4	41.3	48.5	48.0	33.1	33.2
Carbonization—Volatile, %	27.0	35.5	30.4	26.1	22.8	19.7	33.9	38.9	24.9	23.4
Carbonization—Fixed Carbon, %	12.0	18.0	20.5	19.3	13.6	21.6	11.5	9.1	8.2	9.9
Carbonization—Carbon, %	24.4	32.8	29.9	27.9	27.7	25.5	28.3	32.3	19.4	..
Carbonization—Hydrogen, %	2.61	3.5	3.26	3.0	2.22	2.11	3.62	4.32	2.26	..
Carbonization, Fe_2O_3, %	2.83	1.43	1.63	3.9	3.4	3.43	7.05	6.33	7.82	8.12
Carbonization, Cu	0	0	0	0	0	0	1.28	1.09	1.16	1.16
Total Sulphur	1.31	2.37	2.78	2.02	1.73	1.31	2.08	1.89	1.70	1.70
Sulphates	0	0	0	0	0	0	0	0	0	0
Fat, %	4.45	5.30	5.4	3.78	3.41	2.41	15.4	19.6	4.90	4.22
Fat, Saponification No.—KOH for 1 Gm. Fat, Mg.	151	148	202	94	214	209	113	100	92	106
Sand, %	47.0	22.4	25.9	40.5	33.6	31.1	27.8	28.4	38.2	38.2
Total Nitrogen, %	1.89	3.5	2.58	1.67	1.87	1.68	1.49	1.61	1.89	1.45
Free NH_3, %	0.21	0.95	0.92	0.16	0.13	0.09	0.16	0.10	0.48	0.17
Final—20 day B. O. D. per Gm. Organic Solids, Mg.	503	736	491	247	252	199	395	367	256	187
O_2 Absorbed by 1 Gm. Elementary C, Mg.	875	1200	805	314	256	322	675	545	433	...
Organic Matter, %	31.4	39.3	36.0	39.9	36.7	38.8	41.5	44.6	30.5	30.6
Soluble Nitrogen Calculated as NH_3 per 100 Gm. Raw Sludge — NH_3	Trace	Trace	Trace	Trace	Trace	Trace	17.6	48.2 8.1	95.6 100.0	75.7 54.7
— N_2O_5	73.7 75.2	71.2 74.3	93.2 91.0	89.1 85.7	69.6 71.8	135.5 130.8	0	0 0	0 0	0 0
— Increase	43.8 45.3	26.7 29.8	31.9 29.7	16.1 12.7	45.8 48.0	96.4 91.7	...	10.2 ..	4.6 9.0	.. ..
— Decrease	.. ..	.. ..	.. ..	.. ..	.. ..	... ...	11.8	.. 29.9	.. ....	7.7 28.7
Sulphates	++ ++	++ ++	++ ++	++ ++	++ ++	++ ++	0	0 0	++ ++	++ ++

tanks and activated sludge from Plant I. Tank C contained the oldest and best digested sludge. Another sample was taken from the drying beds. The sludge from the Hattingen Treatment Plant was obtained from the drying beds and from the Imhoff tanks, which contained fresh solids and sludge from the submerged contact aerators. The sewage flowing to the Menden Plant contains copper, oil and grease so that digestion proceeds very slowly. The results are shown in Table III. Whereas the volatile substances, carbon and hydrogen decreased during digestion, the fixed carbon increased. There seemed to be no direct relation between the B. O. D. and the carbon content. During the B. O. D. determinations sulphides were oxidized to sulphates.

Modern Settling Tanks Without Sludge Removal Apparatus

DR. ING. M. KUSCH, Berlin-Lichterfelde-West

Gesundh.-Ing., **55**, 145 (1932)

ABSTRACTED BY G. P. EDWARDS

Since German sewage is generally very concentrated and easily becomes septic, settled solids must be removed as quickly as possible from settling tanks. Clarification tanks equipped with sludge scrapers are not satisfactory as the sludge remains in the tank too long (up to 4 hours) and the fine suspended matter does not settle but passes out with the effluent. The moving parts of the apparatus are subject to wear, requiring constant attention and maintenance. The power cost for continual operation is relatively high and the sludge collected is very thin, concentrating very little in the collection sump.

The Kremer settling tanks are hopper bottomed with steeply sloping sides. At the bottom of each hopper is a deep shaft called a sludge cylinder. The settling solids sink into the sludge cylinder where on standing they concentrate to about 83 per cent moisture. Only 10 minutes each day is required for drawing sludge. There are no moving parts in the liquid.

Kremer tanks have been installed in eight municipal treatment plants. The largest individual tank, constructed at Nordhausen, is about 98.4 ft. long, 19.7 ft. wide and is equipped with 5 sludge cylinders. The effective settling capacity is about 14,100 cu. ft. which amounts to about 1.5 hours' settling for the flow from 30,000 inhabitants. Tests have shown that 99 per cent of the settleable solids are removed. Other tanks have been installed at Ratibar, Ziegenhals and Eberswalde.

Use of Activated Sludge Process Increasing

Civil Engineering, **2**, 167 (February, 1932)

ABSTRACTED BY FRANK C. TOLLES

The paper is by Wellington Donaldson and was presented before the Sanitary Section of the American Society of Civil Engineers at the Annual Meeting in January, 1932. Under the title as given the paper devotes considerable attention to sludge bulking, although bulking is not regarded as much of a factor in large works which receive a dilute or well settled sewage.

Bulking is defined as "that condition of the sludge in which the settleable solids by volume are abnormally high compared with the weight." Bulking results in an increase of solid matter in the effluent from sludge settling tanks.

There is lack of agreement as to the cause of bulking, but the explanation offered is that of the presence of an excessive quantity of filamentous bacteria of which *sphaerotilus* is characteristic. This growth causes the sludge to become "fluffy, non-settling and non-compacting."

Factors which contribute to sludge bulking are probably variations in organic load, reduced aeration period and short circuiting. Air supplied, within limits, does not appear critical. The "leakage" of organic matter from the aeration tanks into the sludge settling tanks provides food for the growth of bulking bacteria. Physical conditions—winds, temperature changes, high velocities—may affect the settling of sludge, but bulking itself is apparently due to a modification of food conditions.

The remedy for observed bulking is to be found in readjusting such plant operating conditions as peak loads, the aeration period, solids in the aeration tank and short circuiting. Flattening or deferring of peak discharges to the aeration tanks through storage or otherwise, the use of baffles to prevent short circuiting, reaeration and reduction in the solids within the aeration tanks are suggested. At Tenafly the occasional use of lime has helped. The lime has been added at the inlet to the aeration tank to obtain a pH of 6.6–6.8 for at least a 4-hour period. Settling tank design is important to proper settling of sludge, but lapses in preceding treatment processes are a more usual cause of failure.

The performances of activated-sludge plants are summarized. The process is becoming more outstanding for large works, but is losing ground in the case of small plants where it is difficult to provide technical control. The process is far from standardized and the results from one plant cannot be translated safely to another. Plant loadings are influenced by the strength of the sewage, by the nature and extent of preliminary treatment, by the relation in amount and strength, between average and maximum flows, and also by industrial wastes. Aerating tank solids approximate

from 0.2 to 0.25 per cent by weight in American plants. Such solids are preferably recorded by weight and the air or power requirements should be noted in terms per capita or as units of oxygen which are supplied to the aeration tanks. Short circuiting in aeration tanks is important, and deoxygenation should be guarded against. Reaeration has a place.

The Design, Equipment and Operation of Small Sewage Works

BY N. S. BOWES

Advance copy. Discussion and review as reported in *The Surveyor*, **80**, 560–1 (1931) and **81**, 81–3 (1932)

ABSTRACTED BY J. K. HOSKINS

This paper was presented at the conference of the Association of Managers of Sewage Disposal Works, held under the auspices of the Public Works, Roads and Transport Congress at London, November 19, 1931. The author outlines in considerable detail the method of sewage treatment he would recommend for a works to treat the sewage of a town of 10,000 population. Such a plant should be simple in design and, as far as practicable, automatic in operation. The discussion is based on an assumed domestic sewage flow of 25 gallons per capita and industrial waste contribution of 50,000 gallons, or a total sewage volume of 300,000 g. p. d.

Type of Works to Be Adopted.—The two outstanding methods of choice for the treatment of such sewage are (1) the bacteriological method with tanks and filters and (2) the bio-aeration or activated-sludge process. The advantages of the first method are its reliability of operation with minimum of expert attention, and its flexibility under varying loads, temperatures and sewage compositions. Disadvantages are the requirement of larger areas for the works and special topography of site to avoid pumping. The advantages of the activated-sludge type are the smaller area and wider range of site topography permitted. The disadvantages are requirements of mechanical power, greater volume of sludge which is also more difficult to handle, the narrower range of flexibility of operation and need of expert attention. Therefore, the bacteriological method would be selected if a suitable site is available. Essential points of the site would include an outlet for the purified effluent, sufficient natural slope of the area and suitable location from the standpoint of odor complaints.

Design of Works.—The strength of the crude sewage is assumed to average about 120 p. p. m. of oxygen absorbed in 4 hours. The plant should generally be constructed in at least duplicate units, should be capable of

treating 3 times the dry weather flow and all above that amount in storm water tanks. The works would include balancing tank, detritus tank with screens, storm water tanks, sedimentation tanks, primary filters with humus tanks, secondary filters with humus tanks and sludge beds.

Suggestions for the design of each of these various units are given and illustrations of certain of the details accompany the article. The capacity of the duplicate detritus tanks should be equal to $^1/_{50}$ the dry weather flow and they should be followed by vertical bar screens spaced $^3/_4$ inches apart. Storm water tanks of the inverted pyramid type are suggested with a capacity of $^1/_4$ the dry weather flow. This effluent may be disposed of on land, preferably trenched and under drained, at the rate of 1 acre per 500 sewered population. The sedimentation tanks, also of the inverted pyramid type and in duplicate, are suggested with a total capacity of 15 hours' dry weather flow. The influent enters through a central downward flow pipe and the drawoff is provided by a weir on all four sides of the tank. Sludge is drawn off at the bottom through a valve. The suspended solids removed should average about 70 per cent; if finely divided, the use of a chemical precipitant may be desirable.

The settled effluent should be fine-screened to prevent grease reaching the filter beds. Mechanical distribution of the effluent is advisable, preferably by automatic two- or four-arm revolving type distributors working on a circular bed. Such sprinklers will require not more than 15 inches head. The filter material should be hard, dense, and have a rough surface, should be from 3 to 6 feet in depth and graded from 2 inch to 1 inch with the top 9 inch layer of $^1/_2$ inch gauge. A total of one cubic yard of filtering material to each 70 gallons of the dry weather flow is recommended. Humus tanks similar in design to the storm and sedimentation tanks and providing two hours' dry weather flow are desirable to withhold the humus from the secondary filters.

The secondary filters are duplicates of the primary ones except that the depth should not exceed 4.5 feet. The filtering medium should be finer, ranging from 1 inch to $^1/_4$ inch at the top, and the capacity increased to one cubic yard per 100 gallons. Dosing syphons and humus tanks for both primary and secondary filters are advisable.

Glass-covered sludge beds and sludge digestion are usually not practicable for small works; hence shallow, underdrained lagoons are suggested, at least three in number, with a total area of from 4 to $7^1/_2$ acres. (Abstracter's work: *Evidently an error.*) Theoretically one acre of lagoon should be provided for each 1000 tons of sludge per annum.

Operation.—Although a plant as herein outlined is largely automatic in operation, attendance is necessary to maintain the various units in proper working order. A resident superintendent with three laborers is the usual complement required.

Discussion.—In the discussion of this paper as reported in the *Surveyor*, several divergencies of opinion were expressed. The assumed 30 gallons' per capita daily flow was thought by Mr. P. G. Lloyd to be too low. The apparent advantage of less area for the activated-sludge method was not realized because of the much higher water content of the sludge, thereby requiring greater areas for further sludge treatment. In detritus tanks the provision of a semi-circular pocket in an ordinary channel to create an eddy gave a cleaner detritus deposit. He also advised that the top layer of the primary filter medium should be $^3/_4$ inch size instead of $^1/_2$ inch and for secondary filter $^1/_2$ inch instead of $^1/_4$ inch. Another speaker criticized limiting the depth of filters to 6 feet and advocated filters of 10 feet depth even at a rate of 275–290 gallons per cubic foot.

The view was expressed that it was immaterial whether open sides or closed sides were provided for the filters. Glass-covered sludge drying beds were stated to be an unjustified refinement that might be replaced to advantage by sludge presses Sludge could be dried effectively at the rate of about 6 persons per sq. yd. of drying area.

Sedimentation tank capacity might be reduced from 15 to 8 hours flow when the pyramid type of design is employed because of the smaller volume occupied by sludge.

The cost of such a "de luxe" plant was estimated to be between £3 and £4 per capita and, under present economic conditions, too expensive.

Gas Works Liquor: Its Composition and Treatment

BY A. KEY

The Surveyor, **81**, 335–7 (1932)

ABSTRACTED BY J. K. HOSKINS

This paper, presented at the Midland District meeting of the Association of Managers of Sewage Disposal Works at Birmingham on February 13, 1932, describes the origin and nature of the various types of liquid wastes resulting from coal gas manufacture and the experiences in treating such wastes both separately and when added to the municipal sewage.

The raw or ammonia liquors, amounting to 30 gallons per ton of coal carbonized, are the condensate from the gas generated in the retorts, together with the wash waters with which the gas has been scrubbed. A typical analysis of such liquor is given, the principal constituent of which is ammonia, present to the extent of about 2 per cent. Sulphides, thiosulphates, thiocyanates, phenols and tar acids also occur in amounts from 0.1 to 0.25 per cent each and contribute to the oxygen absorptive value of the liquor given as 10,550 p. p. m. (4 hr. at 27° C.).

Because of its value as a by-product, the ammonia is usually recovered as ammonium sulphate by means of steam being blown through the ammonia liquor. The residual or spent liquor is very low in ammonia. The steam containing the ammonia is passed through hot sulphuric acid whereby the ammonia is absorbed. The steam condensate is known as "devil liquor" and amounts to about 5 gallons per ton of coal. The oxygen absorptive value of devil liquor is higher than that of spent liquor because of phenols carried over by the steam. It can be treated separately, but is frequently mixed with the spent liquor. An analysis of this mixture indicates, among other features, an oxygen absorptive value of 6700 p. p. m. These values apply to liquors from horizontal retorts and are very appreciably increased, especially the higher tar acids, where vertical retorts are used.

Although local conditions modify the volumes of gas works liquors and total sewage flow, the relative amounts, with few exceptions, balance out and with exceptions the spent gas liquor constitutes about 0.4 to 0.5 per cent of the volume of sewage and the ammonia liquor about 0.3 to 0.4 per cent. The oxygen absorption of the sewage is increased about the same by the gas works liquor regardless of whether spent or ammonia liquor is discharged; assuming, of course, that the liquor is added to the sewage at a uniform rate. This is usually the case with ammonia liquor but the spent liquor is periodically discharged because ammonia is recovered generally only at intervals of a month or more.

Gas works liquors can be treated and oxidized in the sewage mixture without harm to biological processes. In America it has been found that sewage mixed with 99 parts of spent liquor is not sterilized, whereas in actual practice the volume of sewage is 99 and that of the liquor less than 1. With ammonia liquors such an extreme experiment has not been tried although there is no reason for believing that the ammonia liquors in reasonable amounts would be detrimental.

Experiments at Oldbury are cited in which as much as 8 per cent of spent liquors in the sewage volume were satisfactorily oxidized at a rate of 15 gallons per cubic yard per day, and where equal volumes of spent liquor and sewage were purified between 90 and 95 per cent. At Coventry spent liquor is treated on bacteria beds with a purification of 80 to 90 per cent. At Cheltenham comparative tests were conducted on the treatment of sewage with and without the addition of spent liquor, which indicated that an increase of 7 in the tank effluent resulted in an increase of less than 0.5 in the final effluent.

The disposal of ammonia liquor has become more acute because of the falling price of the recovered ammonia, making it unprofitable to extract the ammonia at the gas works. However, the only effect of this contained ammonia when added to the sewage is an increase of 20 or 30 p. p. m. in the

free and saline ammonia content of the sewage, which amount should not prove harmful. Laboratory evidence indicates that oxidation of sewage by the activated-sludge process is not materially affected by this added ammonia. Further information is to the effect that the various constituents of gas works liquor are oxidized at different rates and that, arranged in the order of increasing difficulty of oxidation, these components are: phenols, higher tar acids, thiosulphates and thiocyanates.

Discussion.—In the discussion of this paper F. R. O'Shaughnessy referred to the work of other investigators which indicated that gas liquors up to 2 per cent of the sewage volume might be admitted to the sewers. With the increasing strength of such liquors resulting from changes in manufacturing processes, lack of care in their discharge had often upset observations. Balanced flow of such liquors to the sewage treatment plant was a prime essential for satisfactory operation. Mr. H. S. Mercer stated that crude ammonia liquor amounting to 1.5 per cent of the sewage flow was being treated satisfactorily at Tipton. After settling, the mixed sewage was applied to filters at the rate of 58 gallons per cubic yard with a resulting purification over the filters of 85 per cent. Other speakers indicated similar lack of difficulty in treating ammonia liquors on filters when mixed with sewage. Mr. J. A. Christian observed that at Leicester when gas liquor was first discharged into the sewers the effluents were badly affected but later recovered and that when the gas liquor was again discontinued there was a similar disturbance with later recovery. In reply to an inquiry regarding the effect of treated gas liquor effluents on fish life the author stated this had not been tested but that it was known that thiocyanate was considerably less toxic to fish than were phenols.

The Ruhrverband

BY REGINALD C. SHAW

The Surveyor, **86**, 291–4 and 297–8 (March 4, 1932) Illus. With discussion.

ABSTRACTED BY J. K. HOSKINS

This address, describing the organization and activities of the Ruhr River Watershed Board, was given at a meeting of the Yorkshire District of the Association of Managers of Sewage Disposal Works held at Wakefield.

The Ruhr Drainage Area.—The Ruhr River of Germany drains an area of 1700 sq. mi. with a population of 1,400,000. The western section and the banks of the main stream are highly industrialized; the remainder is mostly forest country. The principal industries are the metal trades, tanneries, textiles and paper making. The Ruhr furnishes the water for

these trades as well as for the domestic supplies of the valley and even of three districts outside the watershed. The conservation of water is therefore of prime importance, and is vested in the Ruhr Reservoir Association. This Association has constructed equalizing reservoirs on the upper reaches of the Ruhr and its tributaries for regulating the volume of water available for industrial and domestic use.

The Ruhrverband.—Increasing industrial and population growth resulted in corresponding intensity of stream pollution to a point where self-purification of the stream was wholly inadequate. Prohibition by police authorities of discharge of sewage and industrial wastes to the watercourse failed to remedy the situation and finally epidemics broke out which enforced the demand for adequate control measures. Dr. K. Imhoff prepared a scheme for dealing with the situation which embodies the formation of an organization responsible for the maintenance of sanitary conditions in the stream. In June, 1913, the law was enacted creating the Ruhrverband. All interests concerned were represented in this federation, the members of which were to subscribe money in proportion to the benefits they would derive from the improvements to be made. The work began in 1914, was interrupted by the war and resumed in 1923, with Dr. Imhoff as chief of the federation staff. Modifications of original plans have been made as experience has indicated such changes to be desirable, such as the replacement of biological sewage purification plants by provision for self-purification processes in the stream itself.

The whole river valley is regarded in its entirety and large works provided to deal with the liquid wastes of metropolitan areas regardless of municipal boundary lines, thereby eliminating expensive duplications of small plants. Moreover the degree of treatment provided in each instance is made conformable to the specific requirements. The methods employed for stream cleaning by the Ruhrverband comprise:

1. The construction and operation of purification plants. There are now seventy of these.
2. Assistance in the sewerage of towns to insure the sewage being collected at certain points and that discharges from cesspools are stopped.
3. The construction of carriers to convey the sewage to the various sewage works and the erection of pumping plants where needed.
4. Assistance with the treatment of trade refuse at trade premises so far as the recovery of usable matter is concerned.
5. Improvements in the river course and in the river water itself so as to improve natural self-purification.
6. Supplementary engineering work such as water-power plants, and the constructional work carried out on behalf of constituents who pay the whole cost.

Sewage Disposal Works.—The standards of purification of sewage works vary according to local circumstances, keeping in mind uppermost the protection of the drinking water supplies of the 3,500,000 people using the Ruhr as the raw water source. The lower reaches of the river are more densely populated and at such points a high degree of purification is required. Because of this wide range of conditions, almost every known process of sewage treatment is used somewhere in the district, the principal types of which are briefly described.

A considerable activity of the Ruhrverband has been the provision of proper sewerage facilities. Wherever possible the brooks and small watercourses are used as open sewage carriers; about 130 miles of such open drains have been constructed. Trade wastes are generally mixed with the domestic sewage and treated at the large works and only in a few instances have separate plants been provided for the treatment of trade wastes.

Self Purification of Water in Artificial Lakes.—It has not been considered possible to effect the required degree of stream purity by treatment of the polluting liquids before their discharge to the river, because of obvious difficulties such as storm water overflows, temporary inefficiency of disposal plants and scattered sources of pollution difficult to control effectively. Therefore it has been deemed necessary to stimulate self-purification in the stream itself by providing a series of eight lakes throughout the course of the river, in which natural biological processes may be effective. The total area of these lakes will be $4^1/_2$ sq. mi. and the capacity 6500 m. g. and will increase the mean time of flow by 11 or 12 days. Two such lakes have been constructed and a third is in progress.

Hengstey Lake, with a capacity of 620 m. g. and a detention period of 34 hours, is the first of these lakes to be completed. It is located below the junction of the Ruhr and the Lenne and provides a mixing and coagulation basin for the highly alkaline Ruhr and acid Lenne waters. The precipitated sludge is removed by a dredge. Because of its length ($2^1/_2$ miles) precipitation takes place in the upper part and biological purification in the lower reaches. Water power is conserved by pumping lake water into a high reservoir at night with superfluous current and then generating electric current from the back flow from the reservoir for use during the day. The lake is also being developed as a pleasure resort and scenic attraction. Beneficial effects of the storage and natural purification during the low water years of 1928 and 1929 are described.

Discussion of Above Paper.—A discussion of various points in this paper indicates disagreement with the policy of reusing water polluted with domestic sewage for drinking water supplies after purification. Moreover, use of polluted lake waters such as that of Hengstey Lake for bathing was not considered favorably. The use of open sewage drains such as those provided in the Ruhr valley would not be approved in England and

might be the source of objectionable odors especially during warm weather. The view was also expressed that continued sludging of the lake beds over a period of years would be a serious problem.

It was also pointed out that German sewage was not purified to the same degree as in England because greater dilution was generally available, especially in the Rhine. The extensive and even arbitrary powers of the Ruhrverband in dealing with contributors of pollution would not be tolerated in England.

Report of American Society of Civil Engineers Committee on Sludge Digestion

Civil Engineering, **2**, 169 (March, 1932)

ABSTRACTED BY FRANK C. TOLLES

Samuel A. Greeley (Chairman), W. L. Havens, C. B. Hoover, C. E. Keefer and John F. Skinner constitute a committee of the American Society of Civil Engineers which has been gathering and codifying data on sludge digestion. In January, 1932, this Committee rendered a report of its findings and embodied certain data into a "Summary Report." *Civil Engineering* for March, 1932, carries an abstract of the Committee "Summary Report." The excerpts herein are taken from *Civil Engineering*.

The subject-matter was divided among ten heads of: (1) General Description, (2) Sewage Characteristics, (3) Types of Sludge Digestion Tanks, (4) Environmental Factors, (5) Quantity and Capacity Computations, (6) Gas Production and Utilization, (7) Sludge Disposal, (8) Operating Routine, (9) Cost Data, (10) Bibliography, Glossary and Appendices. Data were obtained in whole or in part from 29 cities, 25 of which are sewered on the combined system. The total population represented by these 29 cities is 4,767,000.

The report presents tables of individual plant data relative to both sewage and digested sludge. The average, maximum and minimum values of these tables, and divided between sewage from combined systems and that from separate systems, are as follows:

	Combined Sewers			Separate Sewers		
	Ave.	Max.	Min.	Ave.	Max.	Min.
Sewage						
Suspended solids, pounds per capita per day	0.265	0.510	0.068	0.158	0.233	0.094
Per cent of suspended solids, volatile	69	79	61	76.5	85	66
Digested Sludge						
Specific gravity	1.04	1.08	1.00	1.03	1.04	1.02
Per cent moisture	91.0	98.7	85.6	93.1	95.0	88.4
pH value	7.0	7.6	6.5	7.2	8.1	6.6
Per cent volatile matter	46.0	63.0	34.4	54.0	65.0	40.5

The major environmental factors which affect sludge digestion are temperature, reaction and age and industrial sewage. Committee findings on the first two of these are as follows:

Temperature.—"1. Up to 125 deg. Fahr., or somewhat more, the time of digestion is decreased as the temperature increases.

"2. There are not enough operating data from large-size plants to justify a final conclusion as to the best and most economical temperature. Present information indicates that temperatures above 80 deg. Fahr. and approaching 100 deg. Fahr. are desirable for digestion. The general over-all economy of any particular digestion temperature should be a matter of local decision. The saving in cost and improvement of operating results with temperatures in excess of 100 deg. have not been established.

"3. The duration of low winter temperatures will affect the relative costs of operation at different temperatures of digestion."

Reaction and Age.—"1. Without a sufficient quantity of seeding material, acid reaction sludge occurs, resulting in delayed digestion.

"2. Settled solids from sewage which has been held for many hours or days, in sewers or plain settling tanks, give an acid reaction.

"3. Solids high in volatile matter from separate sewerage systems tend to produce greater acidity than solids from combined systems.

"4. Liming is not recommended for normal operation, but may be of benefit for acceleration of digestion of acid sludge.

"5. The seeding value of ripe sludge is independent of its moisture content within normal limits, but is somewhat dependent on its age.

"6. Completion of digestion may be determined by physical and chemical characteristics of the sludge.

"7. The nature of the initial solids and the degree of digestion measured by the loss of volatile matter are apparently more important than the depth or type of the tank."

In the matter of quantity and capacity the report includes formulas for computing digestion and storage capacities and to accord with the operating procedures of:

(*a*) Continuous operation and daily withdrawal of sludge.
(*b*) Complete digestion and larger storage of sludge.
(*c*) Uncontrolled digestion and long sludge storage through cold weather.

Under observation of the Committee, particular data for a six-month period were obtained from controlled runs at the separate digestion plants of Grand Rapids and Elyria. The Grand Rapids digestion tanks receive sludge from combined sewers and from primary tanks with an average displacement period of two hours. The tanks have fixed covers and are equipped with stirring mechanisms. At the Elyria plant the diges-

tion tanks receive sludge from a mixed sewage (partly combined, partly separate), and excess activated sludge is mixed with primary sludge in two-story preliminary settling tanks. Average temperatures of digestion at the two plants were 85.6° F. for Grand Rapids, and 70° F. for Elyria. Gas was produced at the rate of 0.79 of a cubic foot per capita at Grand Rapids and 0.5 of a cubic foot per capita at Elyria. From the results of the six-month run, a solids balance in the following values (quoted from Table IV of the article) was derived:

Dry Suspended Solids	Weight in Pounds Grand Rapids	Elyria
In digestion tanks at beginning of test period*	1,029,050	230,620
Introduced into the digestion tanks from the primary settling tanks** during the test period	3,093,750	679,800
To be accounted for	4,122,800	910,420
In digestion tanks at end of test period	1,331,600	308,060
In sludge removed from the digestion tanks	1,811,990	154,170
In sludge supernatant withdrawn from the digestion tanks	213,260	56,510
In gas as equivalent weight	1,247,895	129,870
Accounted for	4,604,745	648,610
Unaccounted for	481,945 Excess	261,810 Deficiency

* Grand Rapids test period, June 16 to October 30, 1931; Elyria test period, April 1 to October 1, 1931.

** Grand Rapids primary tanks are square and equipped with traction type mechanisms; Elyria primary tanks are of the two-story type.

It is to be noted that the Grand Rapids plant in addition to treating sewage as such, also received some lime sludge from the water filtration plant.

Trickling Filter Loadings

Civil Engineering, **1**, 1391 (December, 1931). With discussions in following issues.

ABSTRACTED BY FRANK C. TOLLES

In the December, 1931, issue of *Civil Engineering*, J. A. Childs and George J. Schroepfer, Chief Engineer and Assistant Engineer, Metropolitan Drainage Commission of Minneapolis and St. Paul, present data from fifteen trickling filter sewage treatment plants in the United States, and analyze the information to indicate the relationship between sewage loading and filter efficiency as measured by the 5-day biochemical oxygen demand.

Filtering results are affected by "sewage characteristics; the method of application; the depth of filter bed; temperature, size, shape and kind of

filtering material; dosing and rest periods; and the type of underdrainage system." The current article disregards all of these, except the strength of sewage and the particular rate of application. The results are plotted in four diagrams which present, respectively, the graphical relationships between:

1. The rate of application in gallons per square foot of filter surface per day, and the per cent reduction in 5-day biochemical oxygen demand.
2. The strength of filter influent and the reduction, both in parts per million of 5-day biochemical oxygen demand.
3. The filter loading and the reduction, both expressed in pounds of 5-day biochemical oxygen demand per square foot of filter surface per day.
4. Rate of application in gallons per square foot of filter surface per day, and reduction in pounds of 5-day biochemical oxygen demand per square foot of filter surface per day, and as adjusted to a strength of 140 parts per million of 5-day biochemical oxygen demand in the filter influent.

From the several plottings of the available data, which are derived from plants located in seven states, both Northern and Southern, and which are based upon the analyses of 24-hour composite samples for from one day to one year, it is concluded that, within reasonable limits, considerable variation in the strength of sewage or its rate of application to a particular trickling filter does not materially affect the percentage reduction in the biochemical oxygen demand, and further, that the percentage reduction in biochemical oxygen demand from influent to effluent is fairly constant over quite wide fluctuations, provided such factors as temperatures remain constant.

Discussions of the original article have appeared in succeeding issues of *Civil Engineering*, as follows:

Roy S. Lanphear (Supervising Chemist, Worcester), **2,** 48.

Mr. Lanphear questions comparisons or conclusions which are based on biochemical oxygen demand determinations for a single day. By illustration he quotes the following results as obtained from Worcester plant records:

Period	Biochemical Oxygen Demand Parts per Million		
	Influent	Effluent	Percentage Reduction
Average for month		17.0	
12 Consecutive days	122.4	12.3	90.0
6 Consecutive days	149.5	17.3	88.5
6 Consecutive days	154.2	22.1	85.7
3 Consecutive days	146.1	27.5	81.2

Mr. Lanphear further states that temperature is a factor to be raised with strength of sewage and rate of filter application. Accordingly, results are to be construed in terms of geographical location.

Spring unloading is responsible for a loss of filter efficiency when the biochemical oxygen demand of influent and effluent are compared. At Worcester the per cent reduction during such periods drops to 70 and irrespective of the load on the filters.

L. F. Warrick (State Sanitary Engineer, Wisconsin), **2,** 111.

Mr. Warrick reports that experimental studies on milk wastes at DeForest, Wis., show that trickling filters can sustain considerable increases in load for short periods of time and with little or no decrease in treatment efficiency as determined by the reduction in biochemical oxygen demand. Continued overloading, however, led to ponding difficulties. From the standpoint of nitrification, increase in filter loading resulted in a loss of filter efficiency.

Determination of biochemical oxygen demand should be supplemented by studies of nitrification when judging filter loadings.

Harrison P. Eddy (Consulting Engineer), **2,** 111.

Mr. Eddy states that the data of the original article are rather meager to justify broad conclusions which should properly be based upon annual averages over a considerable period and preferably during years when an effluent of uniform quality is produced. This latter condition is one which reflects the purification needs of a particular plant as imposed by the requirements of the stream into which the effluent is discharged. It would be expected that more extended data of the kind given in the article would show a reduction in filter efficiency with increased loading. Mr. Eddy interprets even the data given as indicating some loss of efficiency with increased biochemical oxygen demand of the filter influent. He cites the case of Decatur which shows an increase in biochemical oxygen demand removal up to a maximum load of 0.11 pound per square foot of filter surface daily, after which the reduction curve drops off. The Burke plant, with packing-house wastes included, shows similar characteristics with the inflection point of the performance curve at about 0.22 pound per square foot per day, while with domestic sewage alone, the curve of filter efficiency drops rapidly with increase of load.

Mr. Eddy also indicates that the biochemical oxygen demand test, while yielding valuable information, is as yet uncertain and affords relatively short time data. The older determinations not only offer the long periods of record which are essential, but the nitrification of ammonia appears to be a more delicate test of performance than the biochemical oxygen demand reduction.

Mr. Eddy refers to Lawrence Experiment Station data on Filter No. 135 which has been in use since 1899. These data indicate that "if a trickling filter is operated for a number of years in such a way as to produce an

effluent of substantial uniform quality, its efficiency as measured by the reduction of free ammonia increases up to a certain point with increased loading. However, when the load is increased beyond that point, its efficiency decreases."

Charles R. Cox (Assistant Sanitary Engineer, New York State Department of Health), **2,** 195.

Mr. Cox points out that a statement of filter performance in terms of "percentage removal" of organic matter serves to obscure the absolute quality of final effluent, a factor which is often critical. He interprets the data of the paper to signify that of "the strength of the influents of even the most efficient of the various trickling filters cannot exceed about 250 parts per million" when a final effluent with a 5-day biochemical oxygen demand of 25 parts per million is desired. For filter influents of greater strength, either the rate must be lowered considerably, or the influent must be diluted.

Although filter performance data are susceptible to straight-line graphical statements in terms of 5-day biochemical oxygen demand of influent and effluent ($Y = X^c$), the data as quoted do not permit of evaluating the composite influence of the many variables indicated by the exponent "c".

Sewage Disposal Plant at Grand Island, Nebraska

BY F. M. VEATCH

Public Works, **63,** 15 (1932)

ABSTRACTED BY C. T. WRIGHT

Grand Island, Nebr., is located on the Platte River approximately six miles from the main channel. The results of studies indicated that a sewage disposal plant, giving a high degree of purification, was essential because the receiving stream offers practically no dilution.

The plant, which has just been completed, comprises screening, pumping, settling, activated-sludge treatment and digestion of the sludge. It was designed to treat the sewage from a population of 25,000 (the 1930 census population was 18,041) and provision is made for its enlargement.

A mechanically cleaned bar screen with half-inch openings is provided, the automatically removed screenings being discharged onto a sloping floor for drainage and then burned in an incinerator fired by gas from the digestion tank. The screened sewage first passes through a grit chamber and then enters a preliminary clarifier with a capacity of approximately two hours' flow. The sludge, concentrated in a central hopper, is pumped to the digestion tank (a remodeled Imhoff tank), which is covered and fitted

with gas-collection domes and heating coils. The temperature of the digestion tank is maintained above 70° F. The four activated-sludge tanks are of the compressed air, spiral-flow type, with a combined capacity of about six hours' flow. The activated sludge is reaerated in a small tank before being applied to the entering sewage. The effluent of the activated-sludge tank enters a final clarifier, circular in form, with central inlet and circumferential overflow weir, having a capacity of approximately two hours' flow.

There are eight sludge-drying beds equipped with a system of overhead carries for removing the dried sludge. This will be disposed of for fertilizer as far as possible.

Jersey City's Boonton Sewage Treatment Plant

Public Works, **63**, 40 (1932)

ABSTRACTED BY C. T. WRIGHT

This plant consists of screens, sedimentation tanks, separate sludge digestion tanks, glass-covered drying beds, contact beds, slow sand filters and disinfection.

There are twelve covered sedimentation tanks, total capacity about 1,000,000 gallons, 100 feet long, 6 feet deep at the outlet end and 13 feet at the inlet end. Each tank contains two roof baffles, one 25 feet from the inlet end, the other 2 feet from the outlet weir. During 1930 these tanks removed an average of 79 per cent of the total suspended solids. After each run, which varies from 4 to 21 days, a tank is entirely emptied and flushed.

The sedimentation tank effluent flows by gravity to five hopper-bottomed digestion tanks. These tanks have a slight V-shaped roof and cylindrical gas collectors from which the gas is piped to a larger gas holder. The hoppers of the five tanks have a capacity of 16,000 cubic feet, with 66,000 cubic feet capacity above the hoppers. These tanks are covered with earth and have a temperature range from 45 to 64 degrees throughout the year. The tanks are unheated at the present time.

There are four sludge-drying beds, under a greenhouse superstructure, covering an area of 11,046 square feet, or approximately one square foot per capita at present loading. The dosage on these beds has been gradually reduced, 9 inches of sludge depth now being the maximum for best results.

The contact beds cover two acres and are made up of two duplicate sets of four units each. The beds are 6 feet deep and are filled with stones ranging in size from $^3/_4$ to 2 inches. These beds have been operated both as contact and as trickling filters. The yearly average suspended solids

content of the effluent is 1 p. p. m. in excess of that of the settling tank effluent. The average increase in dissolved oxygen is 4.4 per cent, and the reduction in nitrites, from about 0.09 to 0.06 p. p. m. A slight reduction in nitrate also occurs.

The sand filters have a total area of six acres, divided into sixteen units. The sand is 30 inches deep, with under drains laid in 12 inches of gravel. The sand has a uniformity coefficient not greater than 4.0, with an effective size between 0.40 and 0.60 mm. Nitrates in the filter effluent showed an average increase during 1930 of 1.2 p. p. m.

The sand filter effluent is chlorinated with an average of 2.04 p. p. m. of chlorine and is retained in two detention tanks with two bays each, providing for a contact period of one hour under maximum loading.

The filter effluent shows a 100 per cent reduction in suspended solids, a dissolved oxygen content of 51 per cent saturation, and a reduction in bacterial content of 97.7 per cent.

After chlorination, the bacterial reduction for 1930 equalled 99.99+ per cent and at no time during the twenty-seven months of the plant's operation has there been *B. coli* in 10 cubic centimeter samples.

The average 37-degree bacterial count of the final effluent was 32 per cc., with a residual chlorine of approximately 0.5 p. p. m.

Report of the Governor's Special Long Island Sanitary Commission

Nassau County—State of New York

May 15, 1931

ABSTRACTED BY S. I. ZACK

General.—A special Sanitary Commission appointed on March 10, 1930, by the governor of the State of New York to investigate the disposal of sewage and garbage on Long Island has submitted this report for Nassau County. The recommendations of the commission are based on a report of detailed studies carried out by the State Department of Health and also advice from the chief engineer of the Long Island State Park Commission and the district state health officer.

Description of Nassau County.—The area of Nassau County is about 275 square miles. Its present population is in excess of 300,000; the population has increased 140 per cent since 1920. Conservative estimates indicate a population of 640,000 by 1940, 980,000 in 1950 and 1,500,000 by 1965. This growth is anticipated because of the geographical location adjacent to New York City and the recreational and residential purposes

provided by the county. The establishment of various state parks along the south shore and in the south part of the county makes it particular necessary for safe and proper disposal of sewage and garbage. Two-thirds of the territory lies south of a ridge about 300 ft. above sea level and drains to the various bays through several watershed valleys.

Existing Sewerage and Sewage Disposal.—Existing sewerage and sewage disposal facilities comprise 13 systems serving 78,000 people in an area of 12,000 acres. Thirty-six pumping stations, which require high operating costs, are in use. Each system is equipped with some form of sewage treatment, such as settling tanks with either chlorinated or unchlorinated effluent discharged to the ocean; and settling tanks or activated sludge with the effluent discharged to ground water. Some of the plants and sewers are already either overloaded or very nearly reaching capacity. Only a few of the interceptors are expected to be large enough by 1950. Most of the treatment plants are operating inefficiently and 8 will require enlargement between 1931 and 1937. The costs of operation of sewers and treatment are excessive and vary from $1.29 to $10.82 per capita per year exclusive of interest and depreciation charges.

The area not tributary to the 13 systems is served by individual cesspools, which are becoming objectionable in the more densely populated sections. Eventually this territory will be equipped with sewers.

Possible Plans for Sewerage and Sewage Disposal.—The municipalities in Nassau County may either continue the present policy of providing sewers or sewage disposal separately for each community irrespective of the other, which has proven costly, inadequate and difficult to operate, or adopt a comprehensive plan which would ultimately provide proper sewage disposal for all. It would be desirable to divide the county into drainage districts, served by interceptors, trunk sewers and treatment works to be built to serve future needs, where present demands require such facilities. Lateral sewers, installed as needed, would conform to the comprehensive plan.

Special legislation is recommended to enable the County Board of Supervisors of Nassau county to appoint a County Sanitary Sewer Commission to determine the needs, and to design, finance, build and operate the necessary plants with the approval of the Supervisors, and further approval of all trunk sewers and treatment plant projects by the State Department of Health.

Garbage, Ashes and Refuse Disposal.—At the present time garbage, ashes and refuse are collected in a majority of the incorporated villages and cities, and various districts are formed for this service in the unincorporated areas. This work is handled by a municipal organization, by a contractor or by private collectors who deal with groups of individual customers. About 1 to 3 pounds of garbage per capita per day are produced in some of

the areas, costing, exclusive of interest and depreciation, from $1.75 to $5.36 per capita per year for garbage collected. Disposal is by incineration or dumping. The incinerator capacity is sufficient to handle garbage from 670,000 people, but because of improper location the capacity cannot be utilized for all the present population. Where figures are available the incineration costs vary from $0.71 to $4.12 per capita per year.

It is desired to secure legislation to create a garbage disposal commission or extend the power to the county sanitary sewer commission with functions relating to garbage similar to those for control of sewage. The purpose of the commission would be to allocate areas for most economical use of present incineration plants and to construct plants for the future.

Beach and Bay Pollution.—Garbage dumped at sea, chiefly by New York as a temporary measure, pollutes the beaches of Nassau County along the south shore and has resulted in a cost of $10,000 per mile of beach for cleaning per season. This will be eliminated by 1934. Meanwhile closer supervision by state inspectors of time and location of dumping barges and effect on beaches is recommended.

Report of the Westchester County Sanitary Sewer Commission

Year from Jan. 1, 1931 to Dec. 31, 1931

ABSTRACTED BY S. I. ZACK

General.—This is the third progress report of the Westchester County Sanitary Sewer Commissioners to the Board of County Supervisors. Five of the eight principal projects of trunk sewers on the program are completed or very nearly completed. These 5 projects now serve an area of 36.6 miles. About 100 square miles are included in the complete project, which will serve the needs for about 50 years in the future.

Three of the four sterilization plants required for elimination of pollution in Long Island Sound and the Hudson River are in operation.

Total appropriations made to date are $23,670,925 of which $15,921,365 has been spent or is under contract. Only about $500,000 of $5,500,000 contemplated will be spent in 1932.

Description of Projects.—The following is a brief description of the project and the stage of completion of each.

The Mamaroneck Valley Project, put in operation in May, 1931, provides sanitary disposal facilities for half of White Plains, almost all of the town of Mamaroneck, the sewer districts of Harrison and large areas in New Rochelle and Scarsdale. Although the sterilization plant was still under

construction, a temporary chlorinator was installed prior to the bathing season of 1931, eliminating a vast amount of pollution in Long Island Sound as shown by daily bacteriological tests. The plant empties through a submarine outlet about $1\frac{1}{2}$ miles from shore.

The Hutchinson Valley Project includes a trunk line draining a densely populated area in lower central Westchester; The Edgmont tunnel; a high level line draining large areas in Pelham and New Rochelle and a low level pumping station, which were put in operation during the latter part of 1931. The pumping plant is equipped with Diesel engines for emergency power. The sewage from the low level area will ultimately be treated in the South Yonkers plant. The obsolete Mount Vernon and Pelham treatment plants will be razed.

The Saw Mill River Project drains an area of 25 miles between Chappaqua and Yonkers. The sewage will be treated in the North Yonkers plant and the effluent discharged to the deep waters of the Hudson River. About one-half of the trunk sewer is either completed or under contract. About three-quarters of the two-mile tunnel connecting the trunk line and sterilization plant is completed.

The South Yonkers Project, which drains a thickly populated section of Yonkers, will be partly in operation in 1932 and when completed will aid in elimination of pollution flowing into the Hudson River at tidewater from 12 city outlets. The sterilization plant at South Yonkers, draining .55 square miles, was put in operation in September, 1931.

Other projects under construction are the North and Central Yonkers Projects and The Blind Brook Project. The sterilization plant of the North Yonkers project will be completed in 1932. The plant of The Blind Brook Project has been in operation 4 years.

Chemical Control.—A chemical and bacteriological control laboratory has been created to study actual conditions in Long Island Sound, and the natural bathing beaches along the Westchester shore, and to aid in close supervision of chlorination at the Hudson River and the various plants.

Operating Costs of Sewage Treatment in North Carolina

Public Works, **63**, 49 (1932)

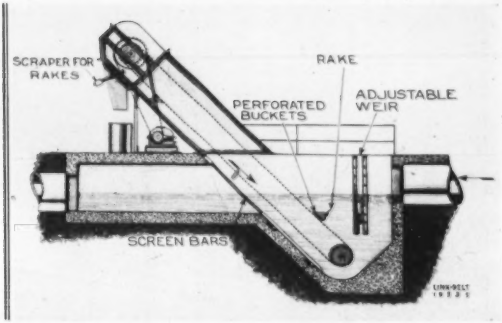
ABSTRACTED BY C. T. WRIGHT

Gastonia, N. C., treats slightly more than a million gallons of sewage daily in an activated-sludge plant using 2.03 cu. ft. of air per gallon at a cost, for plant operation, of $54.33 per million gallons, or $41.86 per 1000 lb. of

dry solids removed. Ferric chloride has been used as a sludge conditioner at the rate of 7.5 lb. per 1000 gal. of sludge. Oliver vacuum filters are used for dewatering sludge.

High Point, N. C., treats slightly more than a million gallons a day of purely domestic sewage by the activated-sludge process, using Oliver vacuum filters and ferric chloride, at a cost of $42.78 per million gallons (about half the capacity of the plant). Power has averaged $850 a month.

Two Charlotte, N. C., activated-sludge plants treat over six million gallons daily, including wastes from dyeing and textile plants. In one plant the sludge is dewatered by Oliver filters; in the other it is treated in digestion tanks. The operating costs average less than $23 per million gallons.



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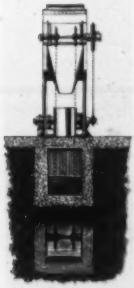

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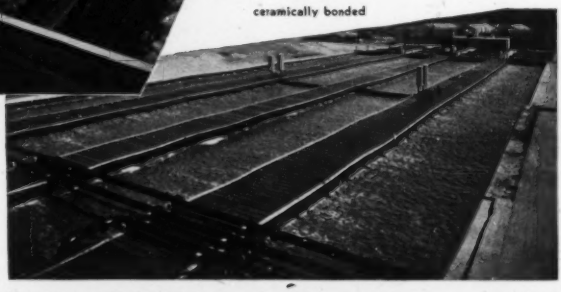

Views of a prominent activated sludge plant. Upper: Close-up showing arrangement of tubes. Below: General view of tanks in operation.

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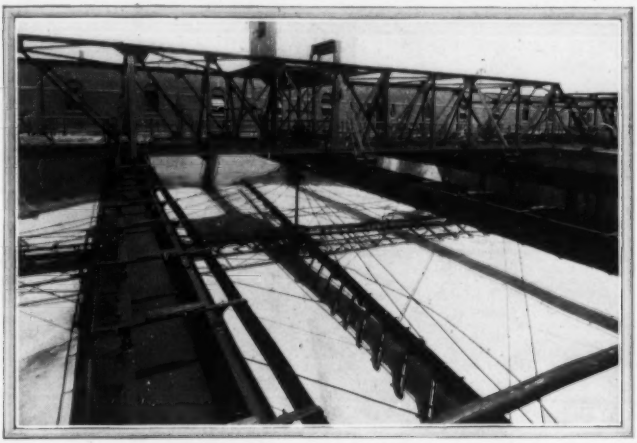

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Statement of the Ownership, Management, Circulation, etc., Required by the Act of Congress of August 24, 1912, of Sewage Works Journal, published bimonthly at Easton, Pa., for April, 1, 1932.

State of New York } ss.
County of New York }

Before me, a Notary Public in and for the State and County aforesaid, personally appeared William W. Buffum, who, having been duly sworn according to law, deposes and says that he is the Business Manager of the Sewage Works Journal and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 411, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor and business managers are:

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Publisher, Federation of Sewage Works Associations, c/o H. E. Moses, Pa. State Dept. of Health, Harrisburg, Pa.

Editor, F. W. Mohlman, 845 South Wabash Avenue, Chicago, Ill.

Managing Editor, F. W. Mohlman, 845 South Wabash Avenue, Chicago, Ill.

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2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.)

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3. That the known bondholders, mortgagees and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: (If there are none, so state.)

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5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the six months preceding the date shown above is: (This information is required from daily publications only.)

WM. W. BUFFUM, Business Manager.

Sworn to and subscribed before me this 15th day of March, 1932.

(Seal) KATHERINE L. GREVES

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(My commission expires March 30, 1932)

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